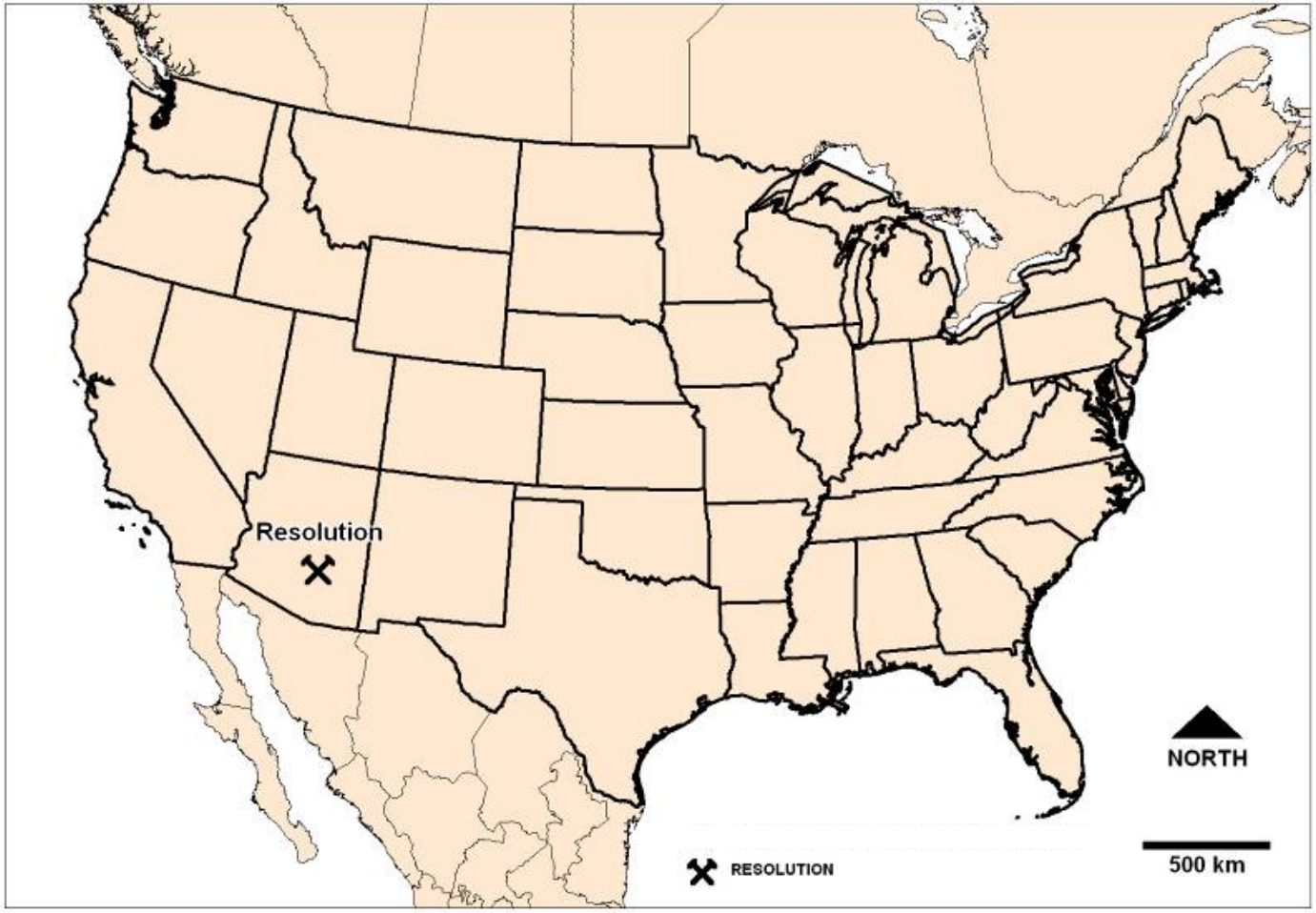
The geology and discovery history of the Resolution porphyry Cu-Mo deposit, Arizona, USA

George Steele, Chief Geologist - Base Metals, Rio Tinto Exploration with acknowledgement of all past and present Resolution Project geologists

Photo: Resolution Copper Mining Limited

Resolution shafts 9 & 10

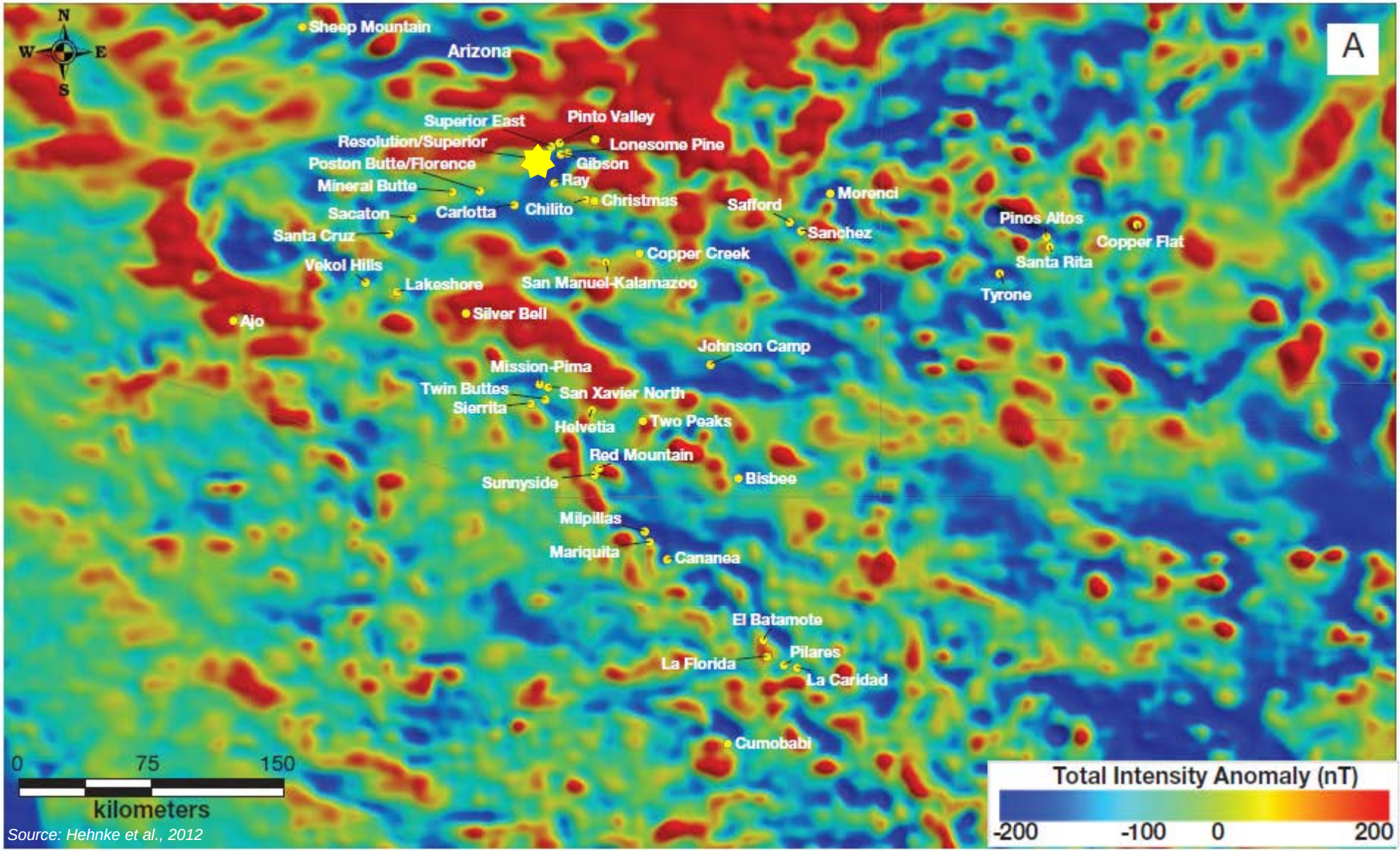
Resolution deposit – location



Source: Resolution Copper Mining Limited

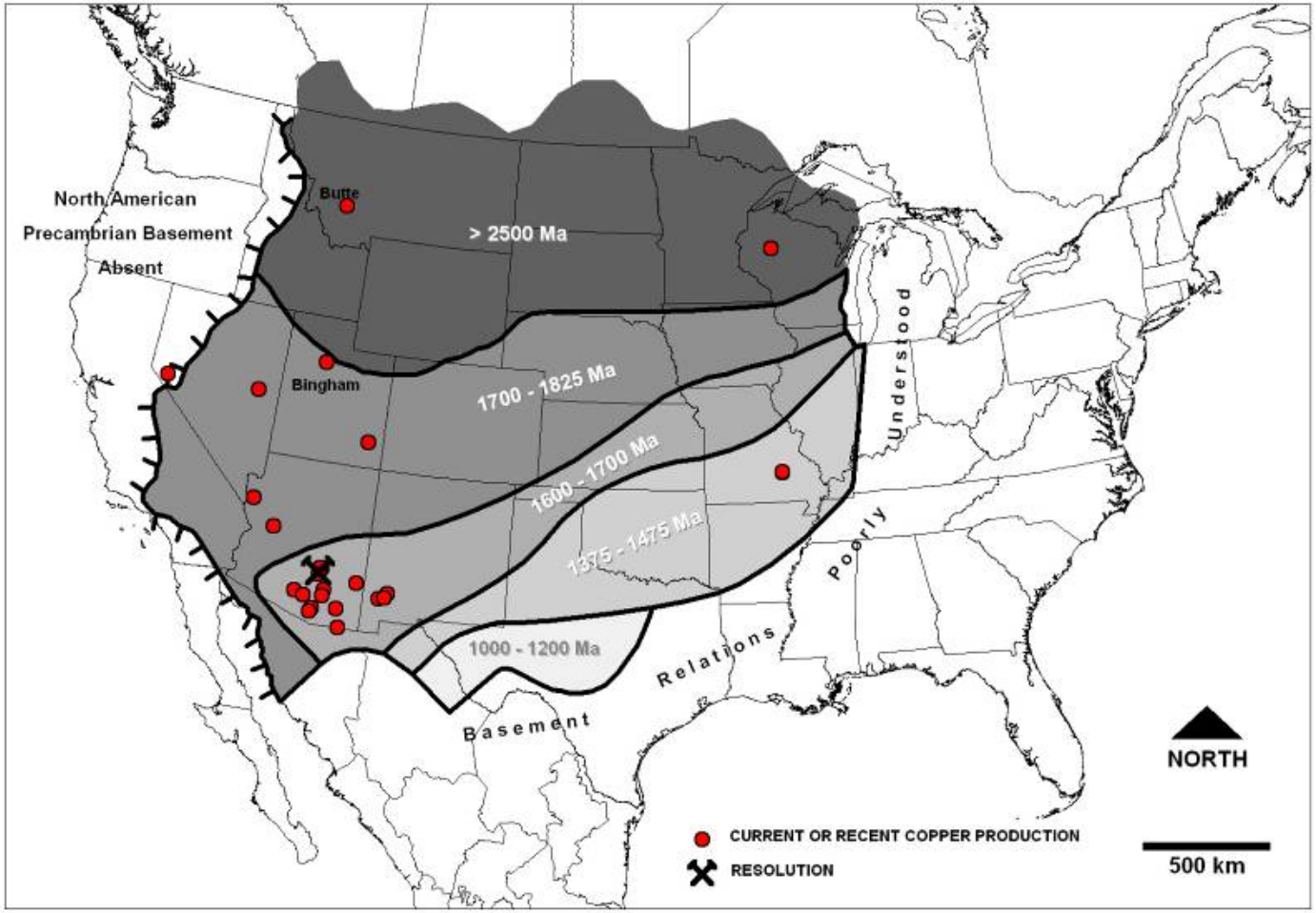
RioTinto

SW USA porphyries and total magnetic intensity



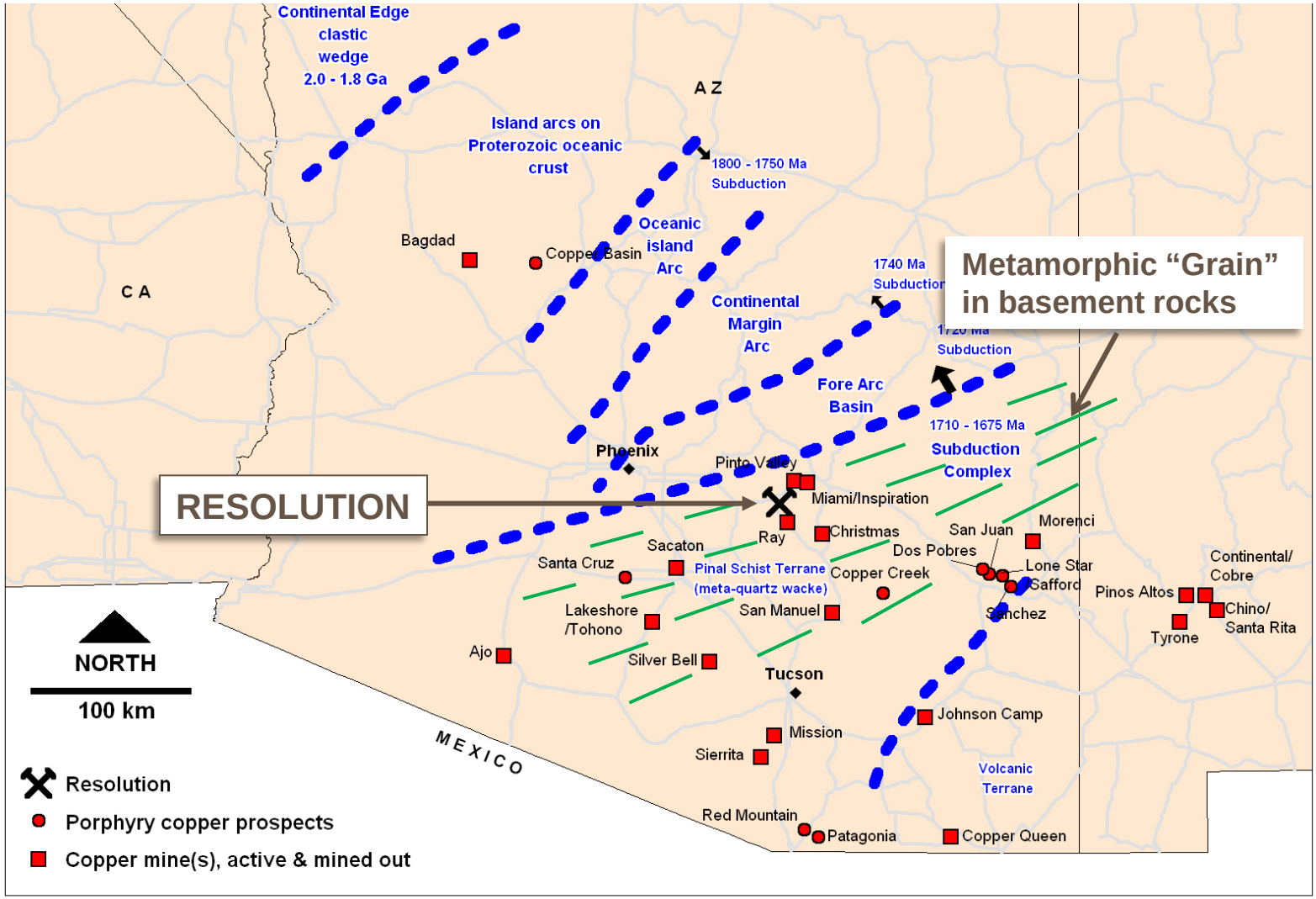
Source: Hehnke et al., 2012

Resolution deposit – basement terranes



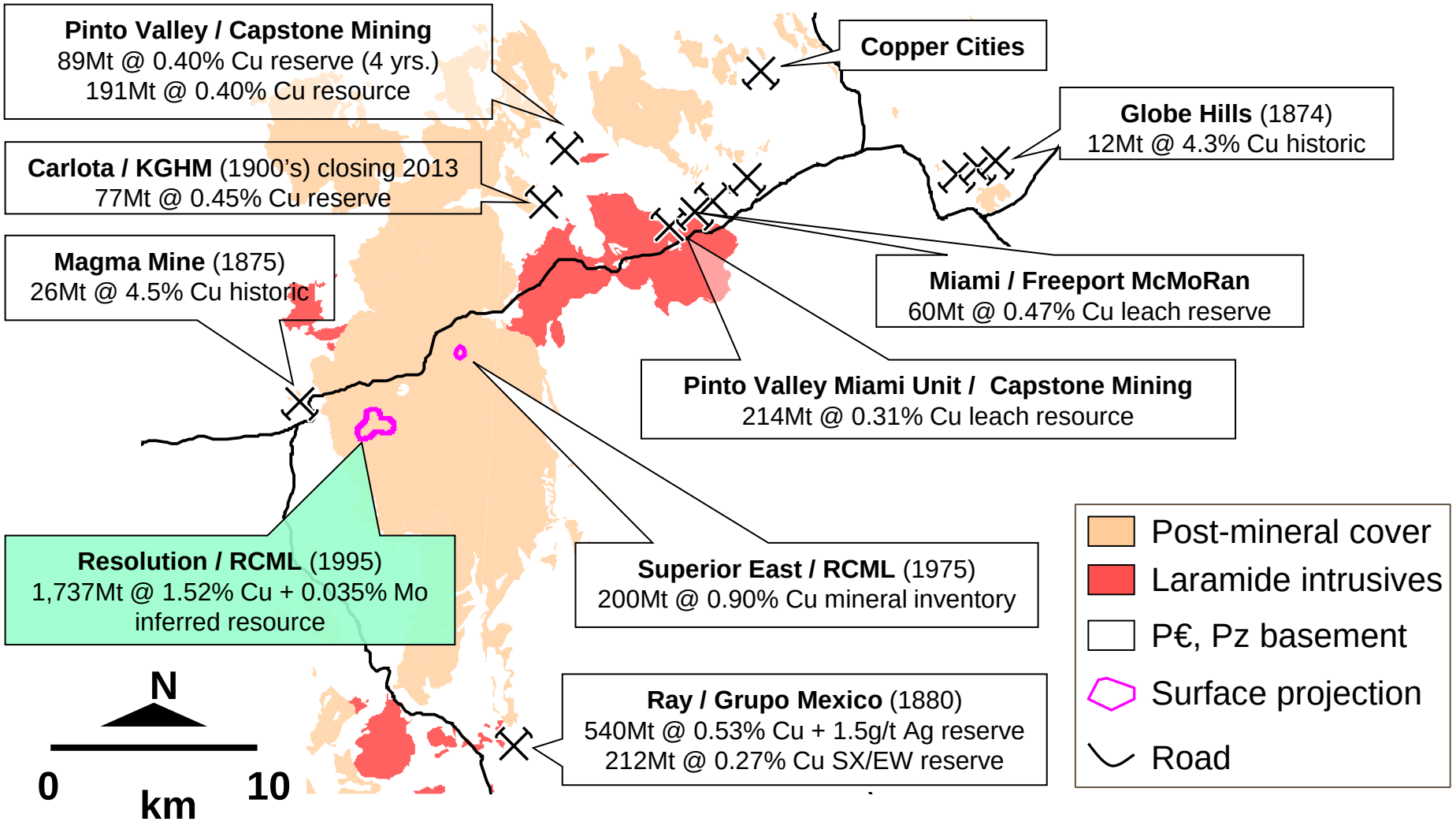
Source: Resolution Copper Mining Limited

Resolution deposit
Proterozoic ENE – trending structural grain



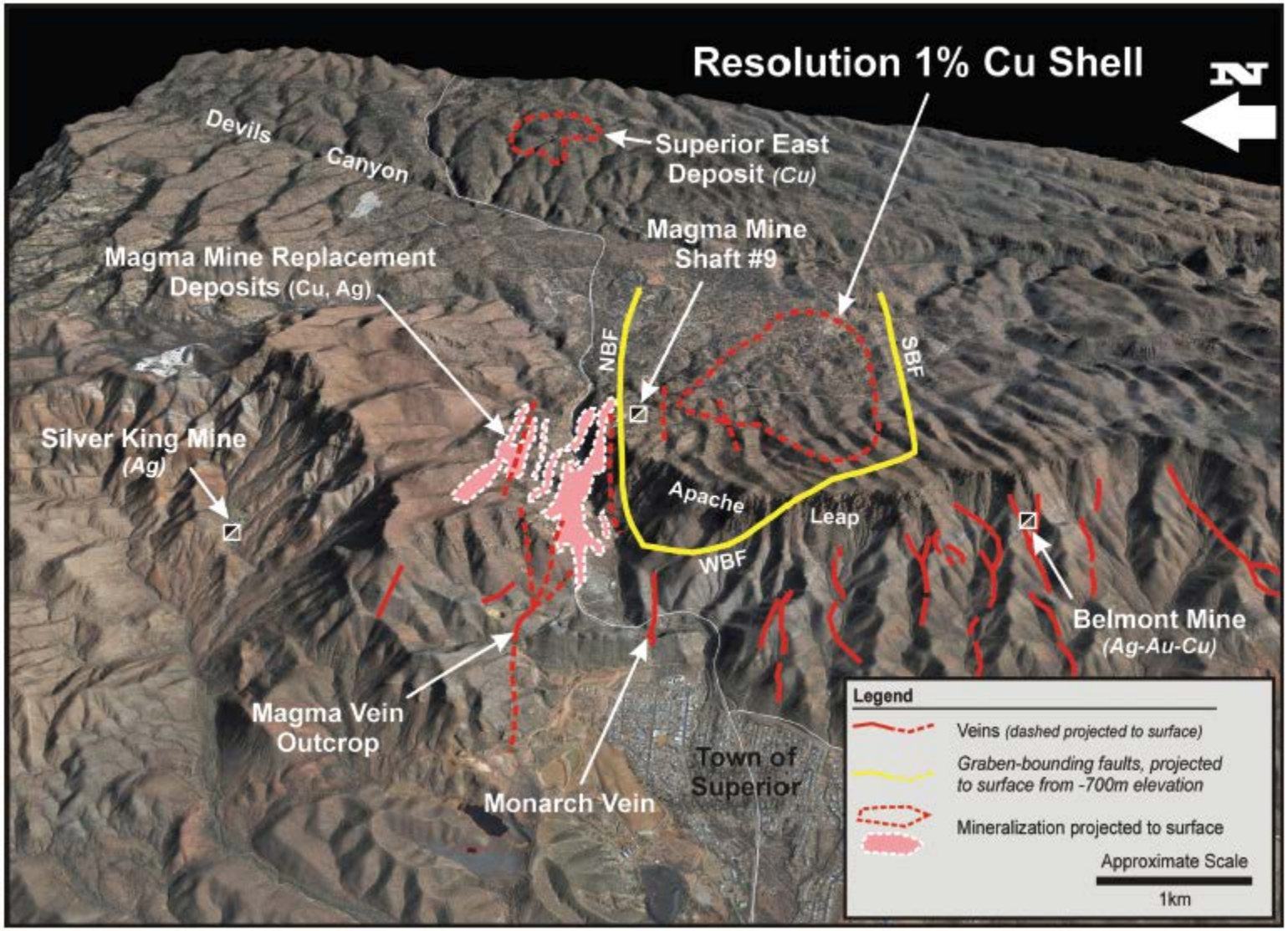
Source: Resolution Copper Mining Limited

Pioneer [Superior] District - resources


Pinto Valley / Capstone Mining
89Mt @ 0.40% Cu reserve (4 yrs.)
191Mt @ 0.40% Cu resource
Copper Cities
Globe Hills (1874)
12Mt @ 4.3% Cu historic
Carlota / KGHM (1900's) closing 2013
77Mt @ 0.45% Cu reserve
Magma Mine (1875)
26Mt @ 4.5% Cu historic
Miami / Freeport McMoRan
60Mt @ 0.47% Cu leach reserve
Pinto Valley Miami Unit / Capstone Mining
214Mt @ 0.31% Cu leach resource
Resolution / RCML (1995)
1,737Mt @ 1.52% Cu + 0.035% Mo
inferred resource
Superior East / RCML (1975)
200Mt @ 0.90% Cu mineral inventory
Ray / Grupo Mexico (1880)
540Mt @ 0.53% Cu + 1.5g/t Ag reserve
212Mt @ 0.27% Cu SX/EW reserve
N
0
10
km
Post-mineral cover
Laramide intrusives
P€, Pz basement
Surface projection
Road

Source: Resolution Copper Mining Limited

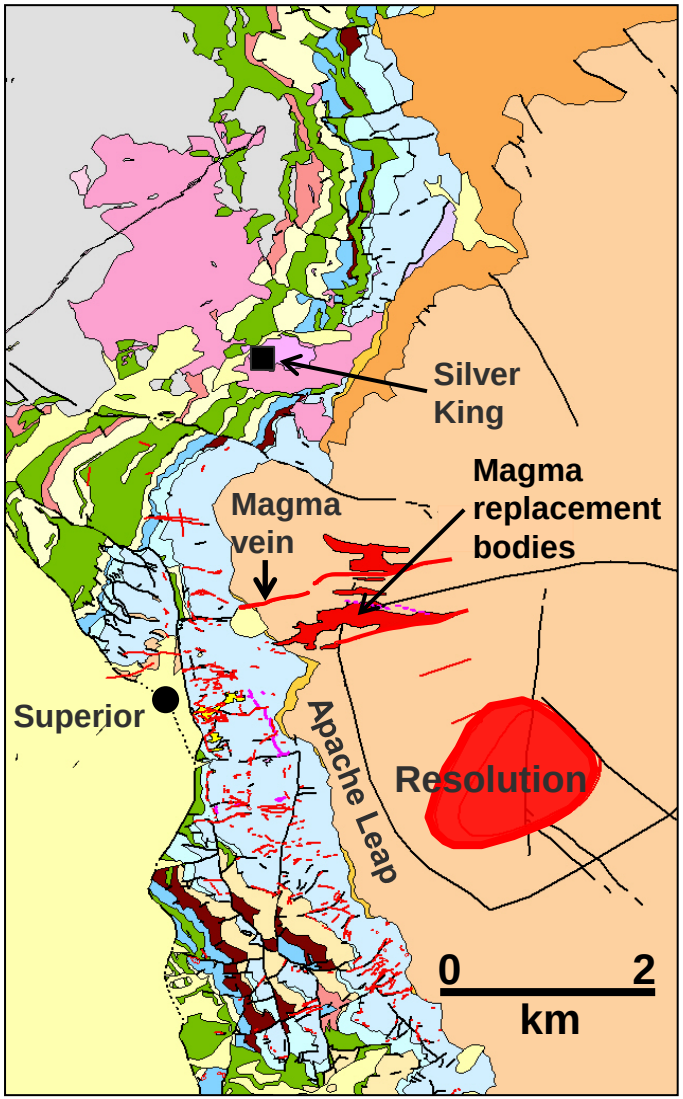
Resolution deposit footprint



Source: Hehnke et al., 2012

Resolution discovery history – early history

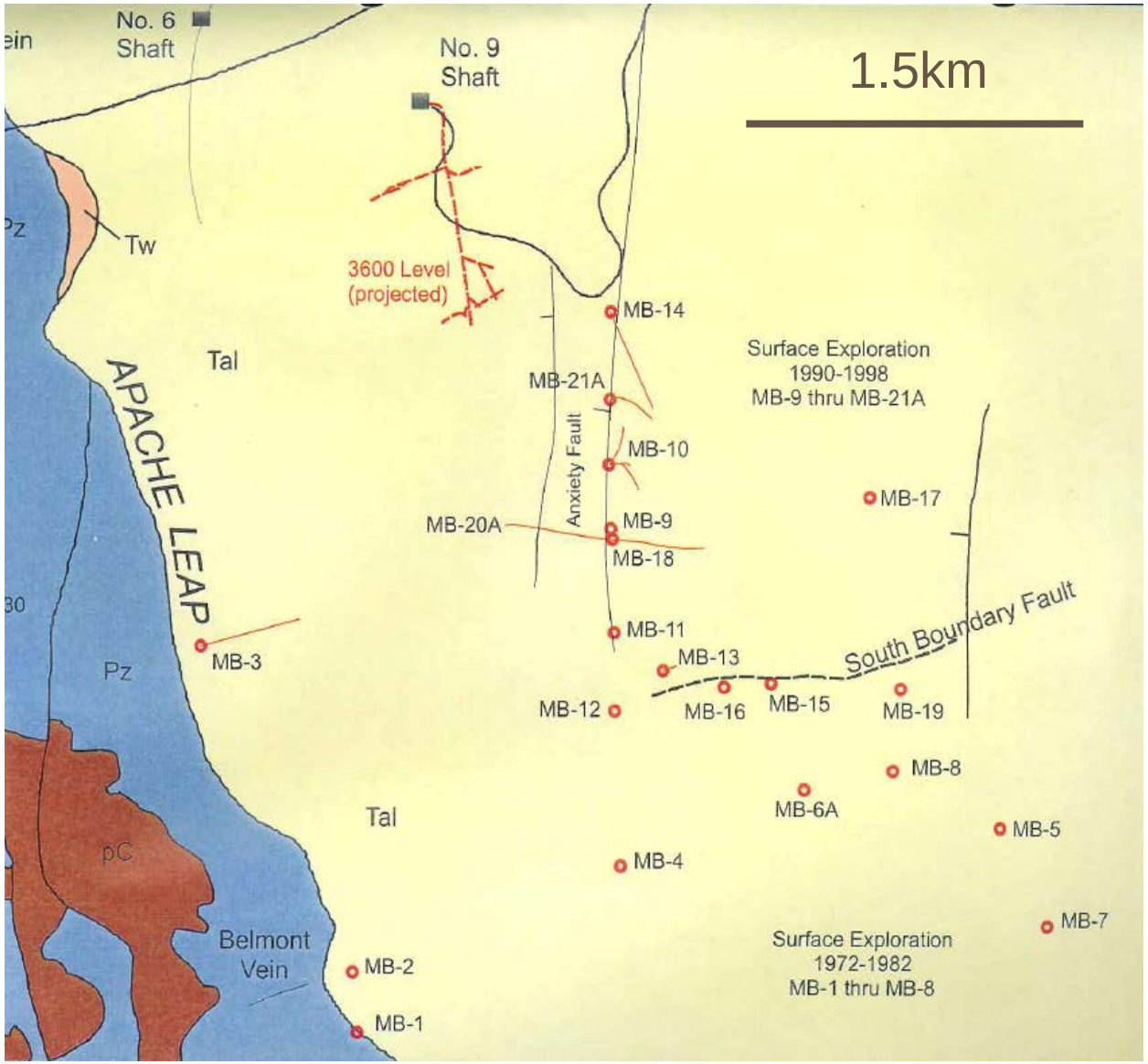
- The Pioneer Mining District was established in 1875 after discovery of native silver at Silver King 5km north of the town of Superior.
- Numerous small workings exploited silver veins in Paleozoic rocks along 8km of outcrop at the foot of Apache Leap. One of the veins, the Silver Queen Vein later became known as the Magma Vein.
- In the early 1900s Silver Queen transitioned into a copper producer as supergene silver ores were depleted. Supergene chalcocite transitions into hypogene chalcocite and bornite at depth.
- Lateral mine development followed the Magma Vein eastward under cover leading to discovery of massive sulphide replacement bodies at favorable horizons within the Paleozoic carbonate wall rocks.
- In the 1960s mine production focused on the replacement lodes. These supported mining operations until reserve depletion in June 1996. The Magma Vein was eventually exploited along a strike length of 3km and to a depth of 1,500m.
- Over 85 years the Magma Mine produced 24.5Mt of ore grading almost 5 percent Cu.



Source: Manske and Paul, 2002

Resolution discovery history
Surface exploration 1990-98; Magma Copper/BHP

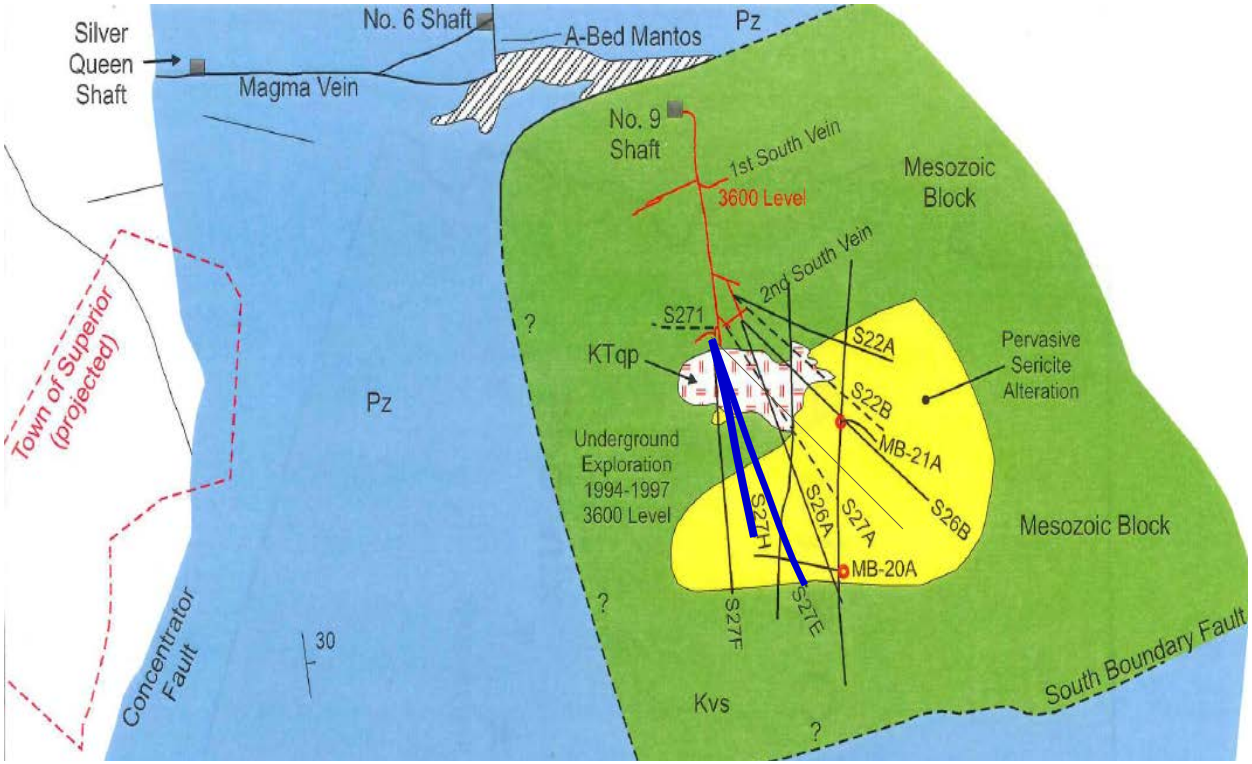
- In 1991, recognizing the imminent reserve depletion in the Magma Mine, a district-scale exploration program was launched for additional replacement bodies.
- Building on district geologic concepts first formulated in the 1970s, exploration focused under the plateau of Apache Leap in the vicinity of the shaft #9 complex.
- In 1991 hole MB-9 was drilled from surface targeting vein mineralisation.
- The hole cut leached cap, a thin enrichment zone and weak pyrite-chalcopyrite-specularite mineralisation in chlorite-sericite alteration and was the first direct indication of (distal) porphyry-style alteration / mineralization.



Source: Manske and Paul, 2002

Resolution discovery history
Underground exploration 1994-97; Magma Copper

- In October 1994, a sub-horizontal drill hole [S27E] was directed southward from the southern most underground mine workings.
- This hole intersected 460m @ 0.56% Cu in quartz-sulphide stockworked pervasively sericitised wall rocks. It was surmised that this drill hole had cut across the high structural level of a concealed porphyry center.
- In January 1996 a follow-up hole [S27H] inclined beneath the "discovery hole" drilled through the sericitic zone into intensely biotitised rocks returning 43m @ 1.94% Cu and 0.037% Mo.



Drill hole	DH interval (ft)	Intercept (m)	Cu (%)	Mo (%)
S22B	2,745–3,080	102	1.14	0.012
S27A	2,210–3,014	245	1.19	0.024
S27H	2,800–2,940	43	1.94	0.037
MB-20A	5,420–6,424[1]	306	1.75	0.029
	5,420–5,805[2]	117	1.06	0.031
	5,805–6,424[3]	189	2.18	0.028
MB-21A	5,080–5,358	85	1.88	0.027

Source: Manske and Paul, 2002

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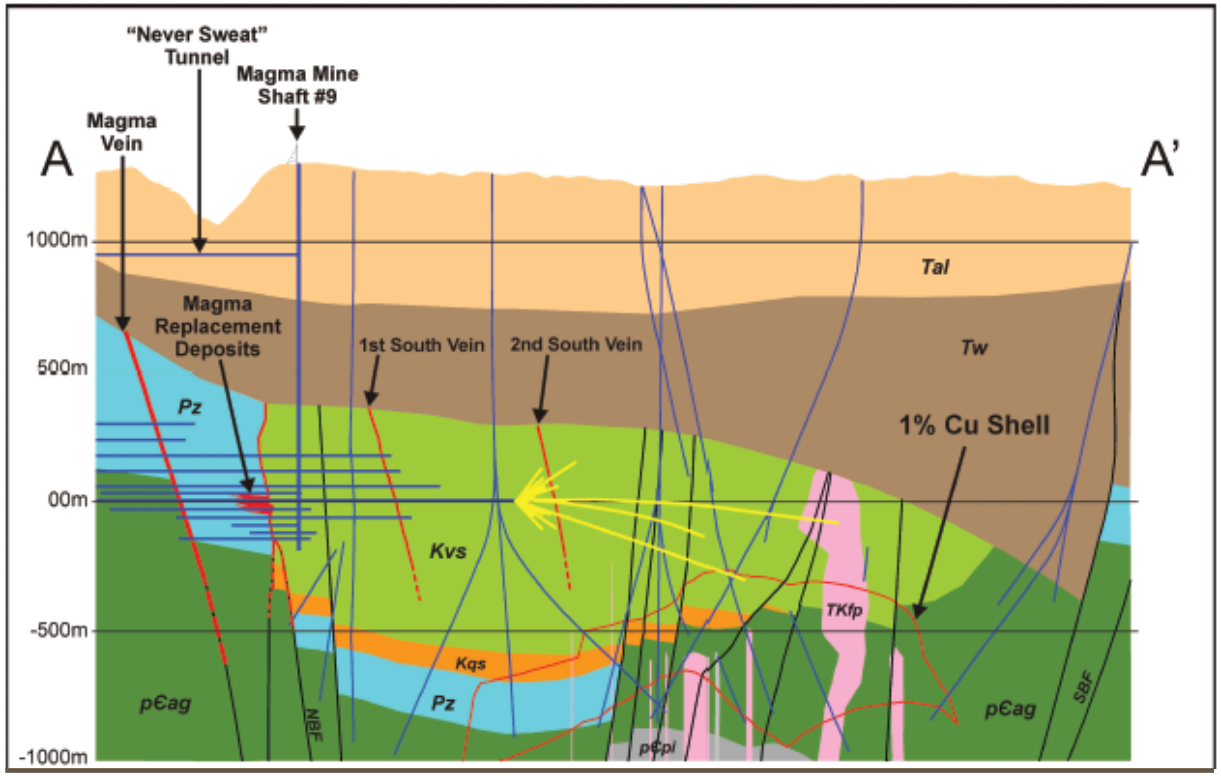

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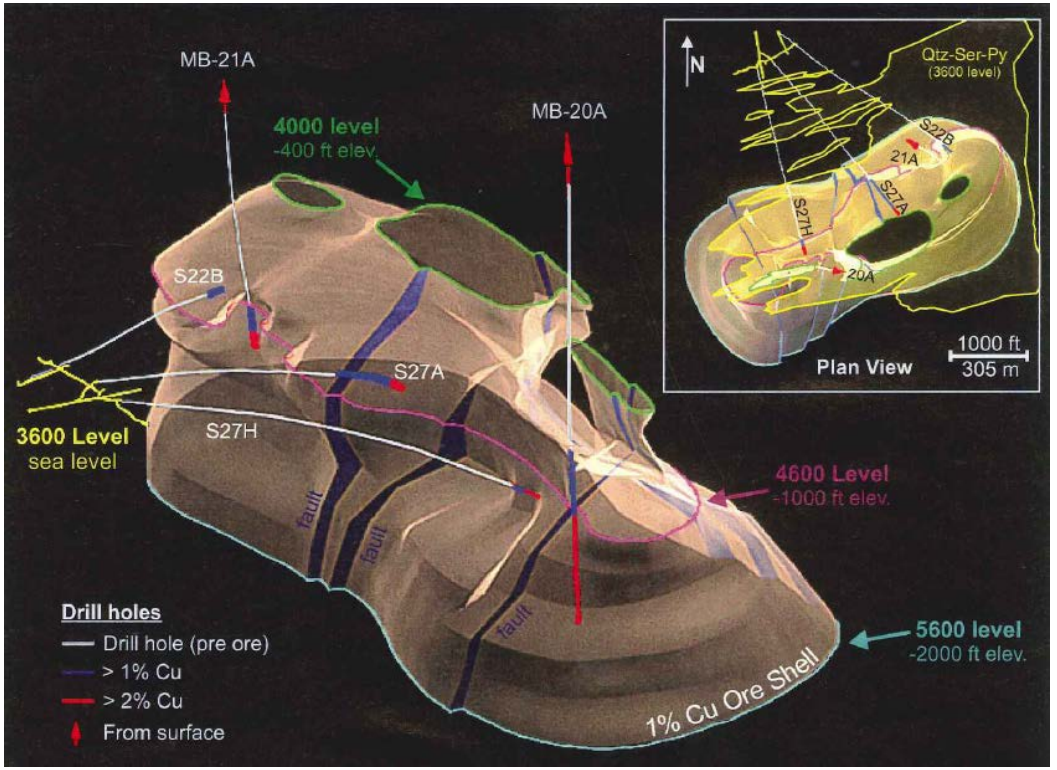
Source: Manske and Paul, 2002

Resolution discovery history
Underground exploration 1996-98; BHP

- In 1996 BHP acquired Magma Copper and mining operations were closed shortly afterwards.
- Exploration drilling continued until the end of 1997.
- In March 1998 a mineral inventory of 415Mt @ 1.66% Cu + 0.02% Mo + 2g/t Ag was announced to the Australian Securities Commission.
- A 750m long x 250m wide x 300m high body of >1% hypogene Cu was modelled with a best intersection of 306m @ 1.75% Cu + 0.029% Mo.
- In 1998 the pumps were pulled from #9 shaft and the shaft was flooded.
- In April 2001 Kennecott (a wholly-owned Rio Tinto subsidiary) signed an option to JV agreement with BHP requiring an initial investment of US$25M to earn a 55% interest.



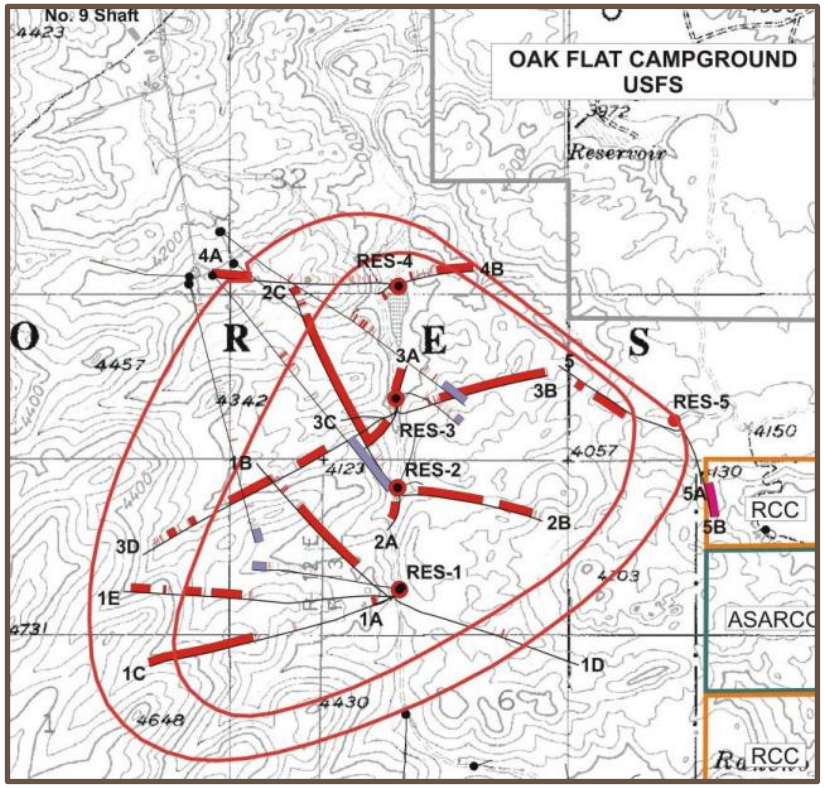
Hole	From (m)	Length (m)	Cu %	Mo %
MB-20A*	1704	306	1.75	0.029
MB-21A*	1548	85	1.88	0.027
S22B	843	102	1.14	0.012
S27A	692	245	1.19	0.024
S27H	850	43	1.95	0.036

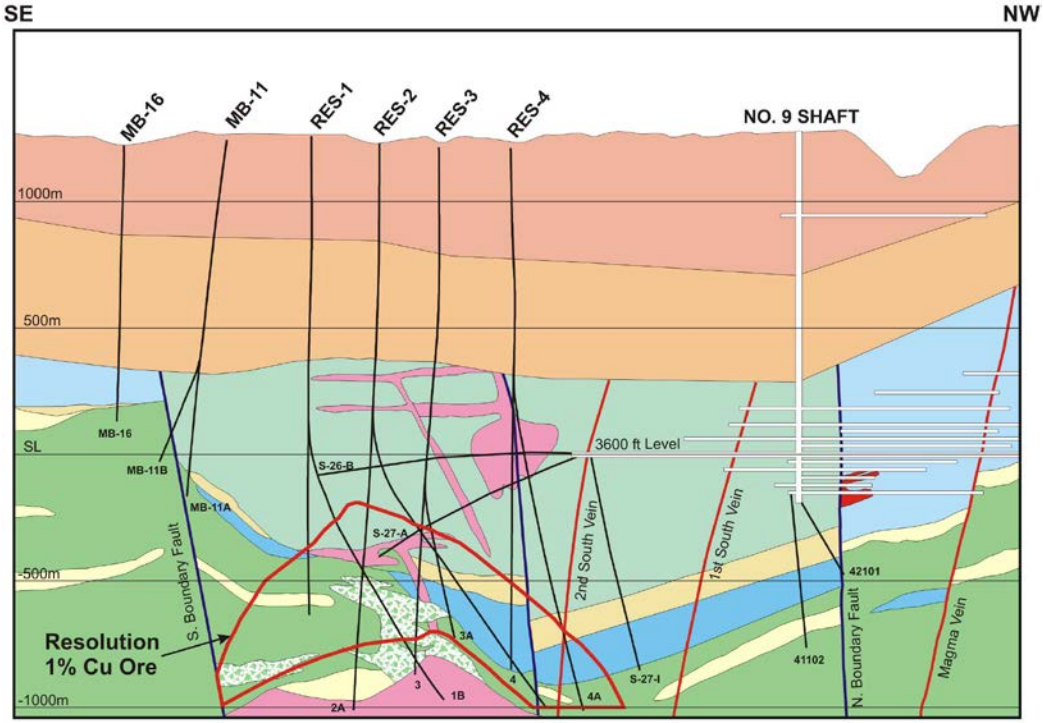
*surface hole

Source: BHP Billiton resource announcement 1998, Resolution Copper Mining Limited

Resolution discovery history 2001-03; Rio Tinto

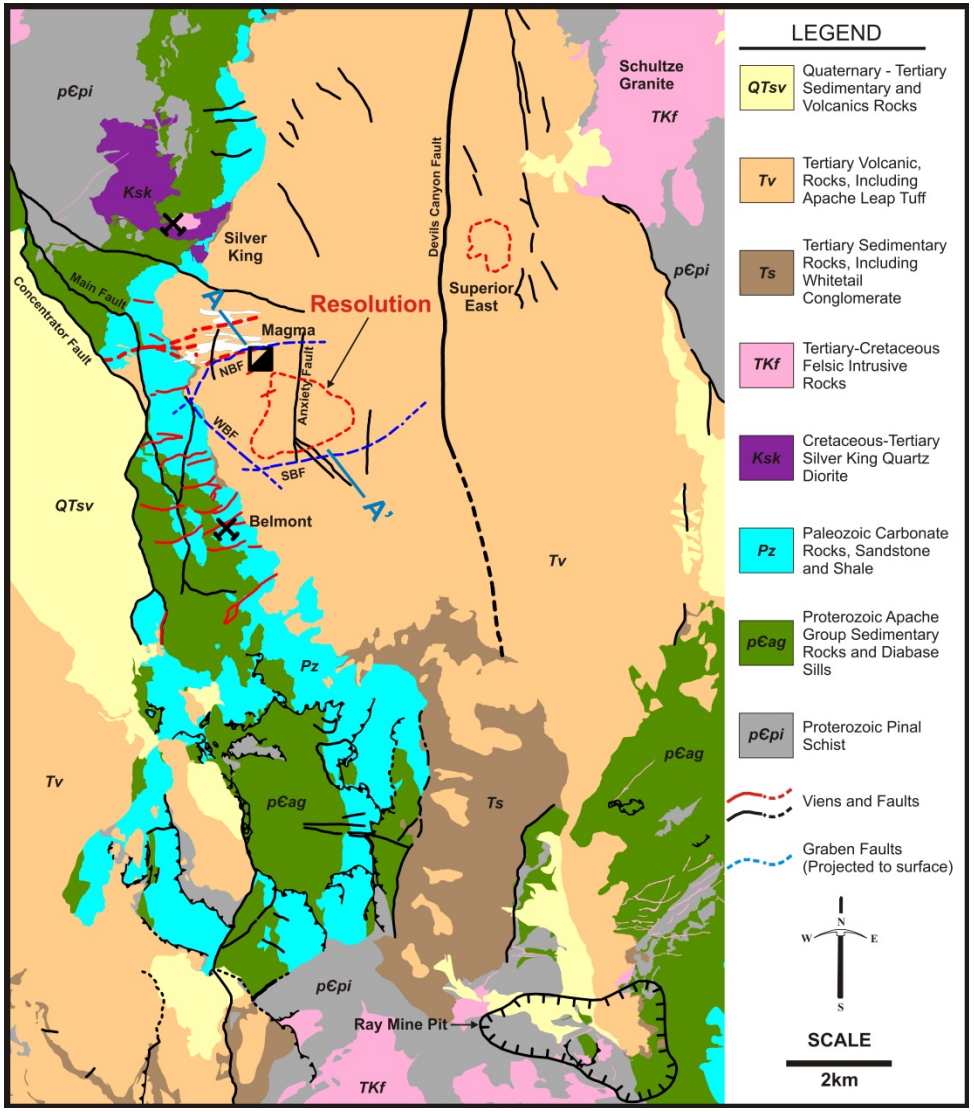
- Completed 17 holes in 18 months
- Five drill sites
- RES-5 returned 352m @ 2.61% Cu & 0.039% Mo
- RES-3B returned 595m @ 2.15% Cu & 0.046% Mo





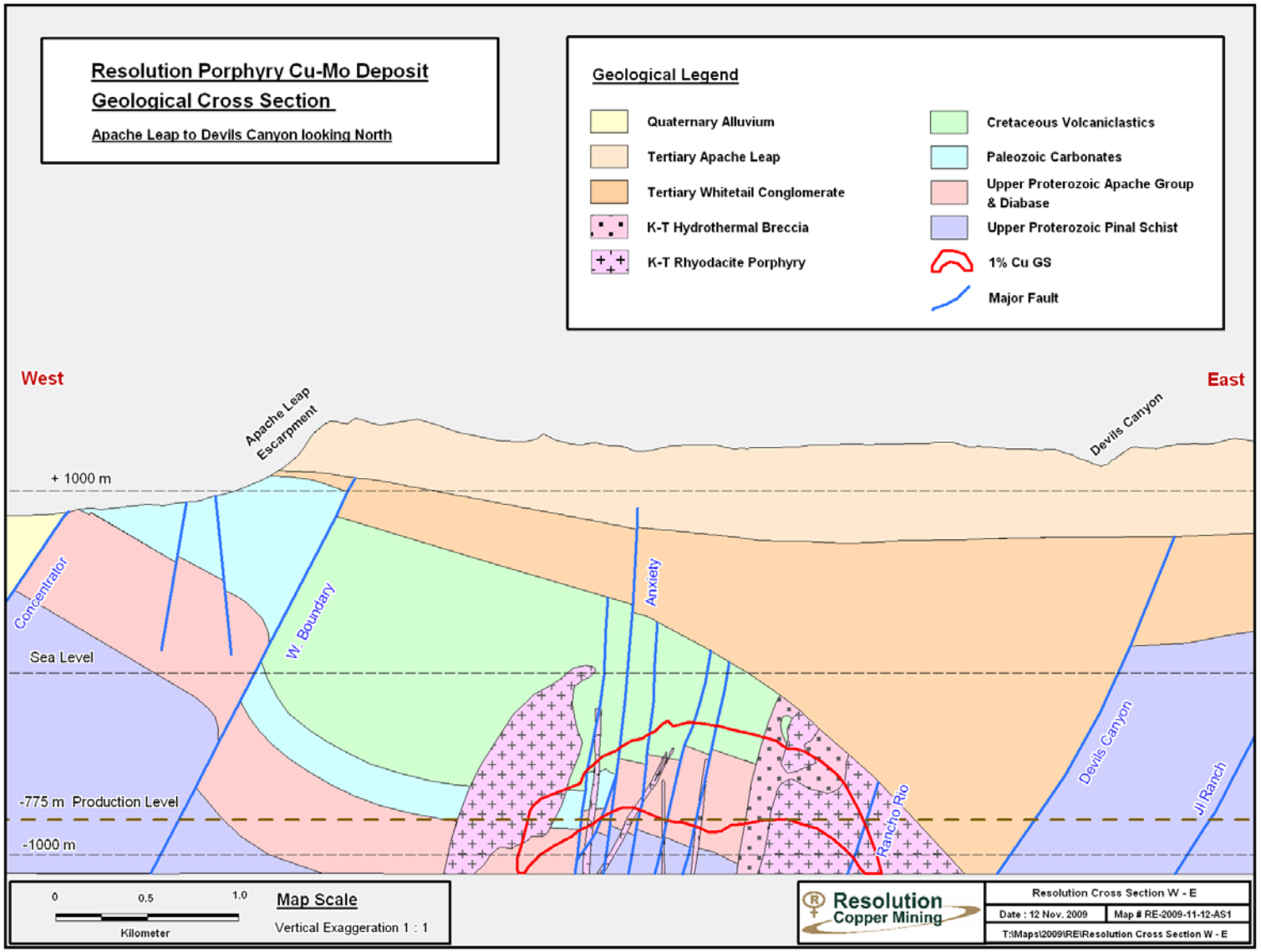
Source: Resolution Copper Mining Limited

Resolution - regional geology



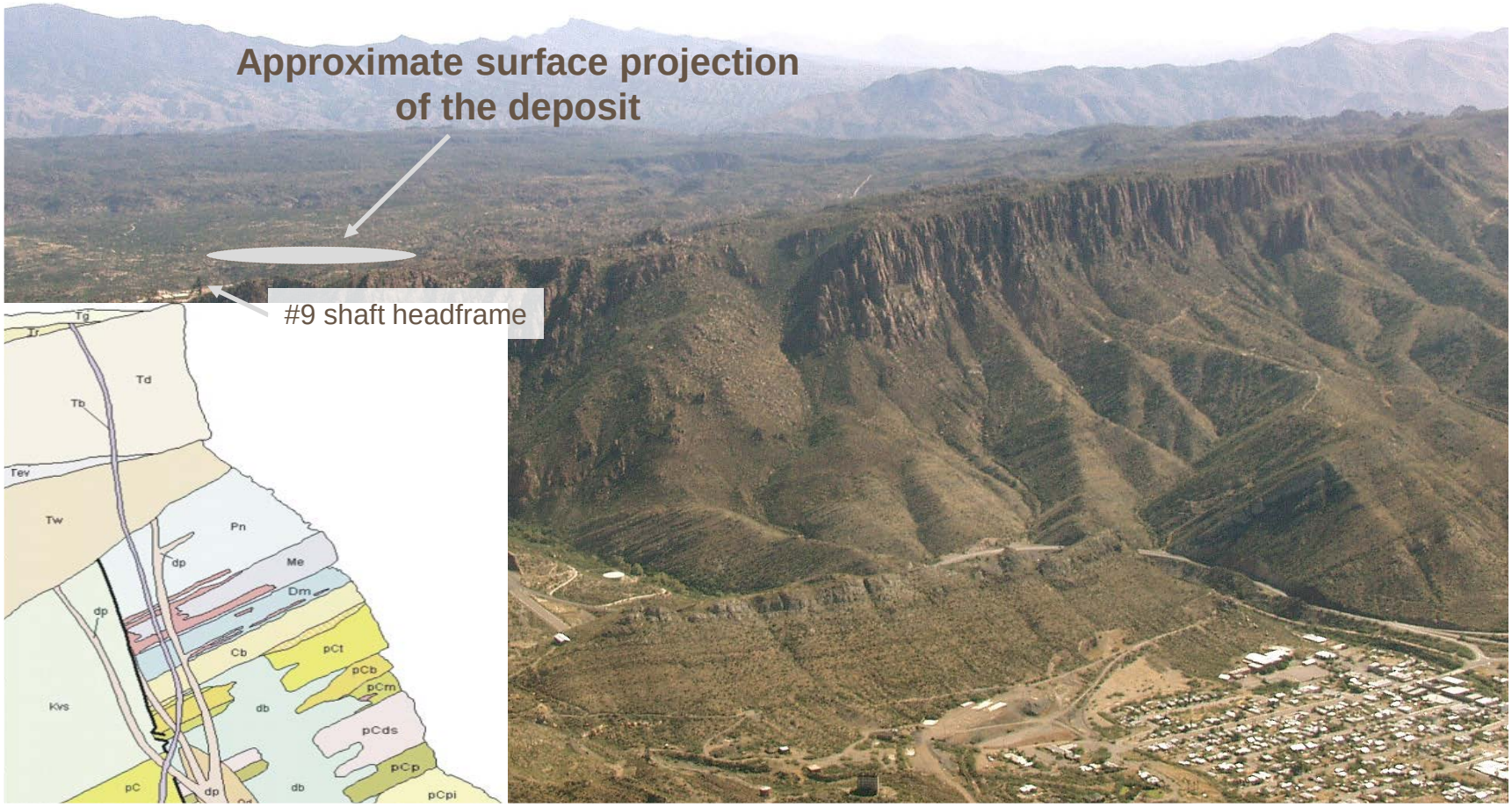
Source: Resolution Copper Mining Limited

Resolution deposit – E-W cross section



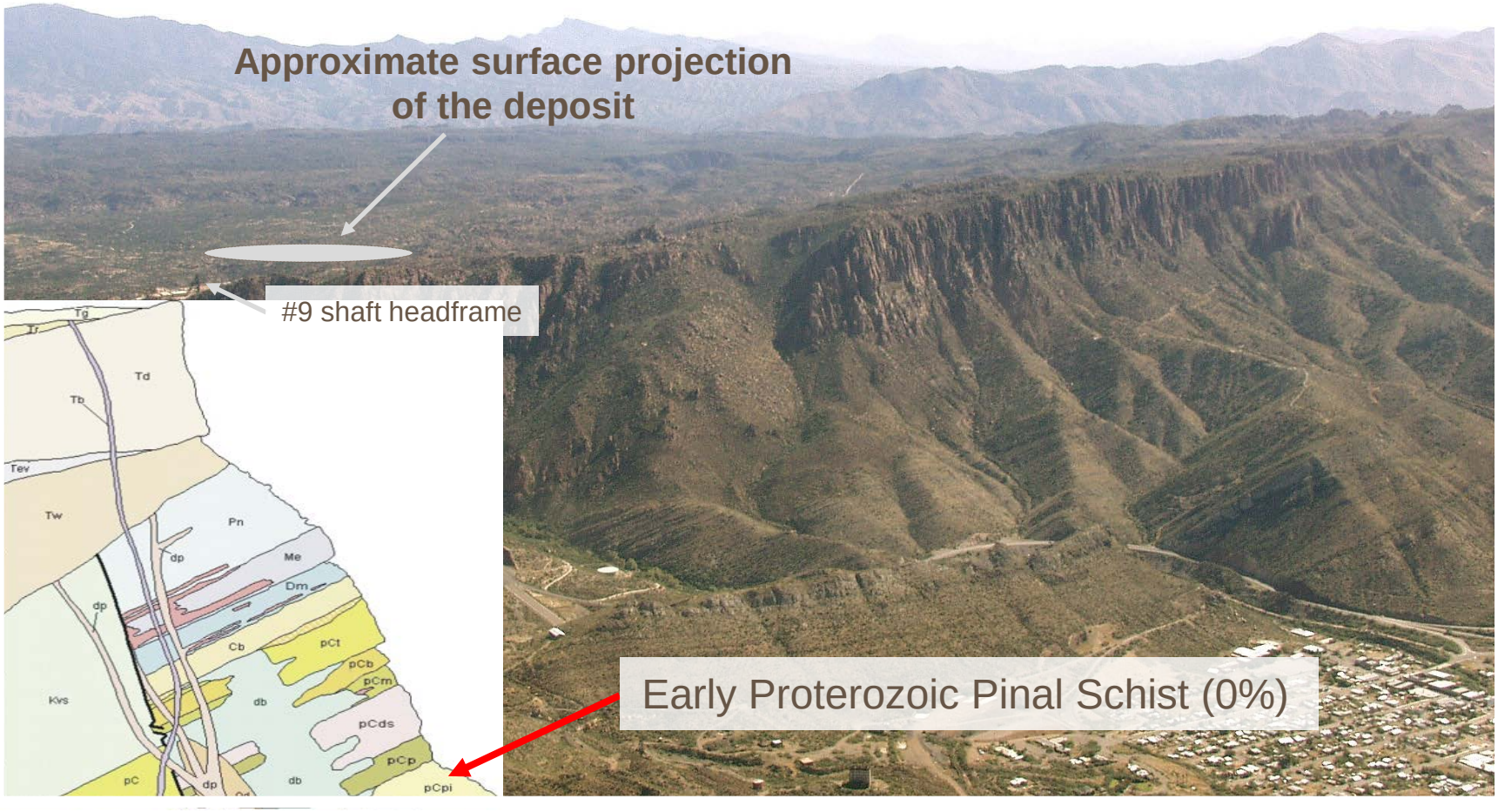
Source: Resolution Copper Mining Limited

Resolution stratigraphy



Source: Resolution Copper Mining Limited

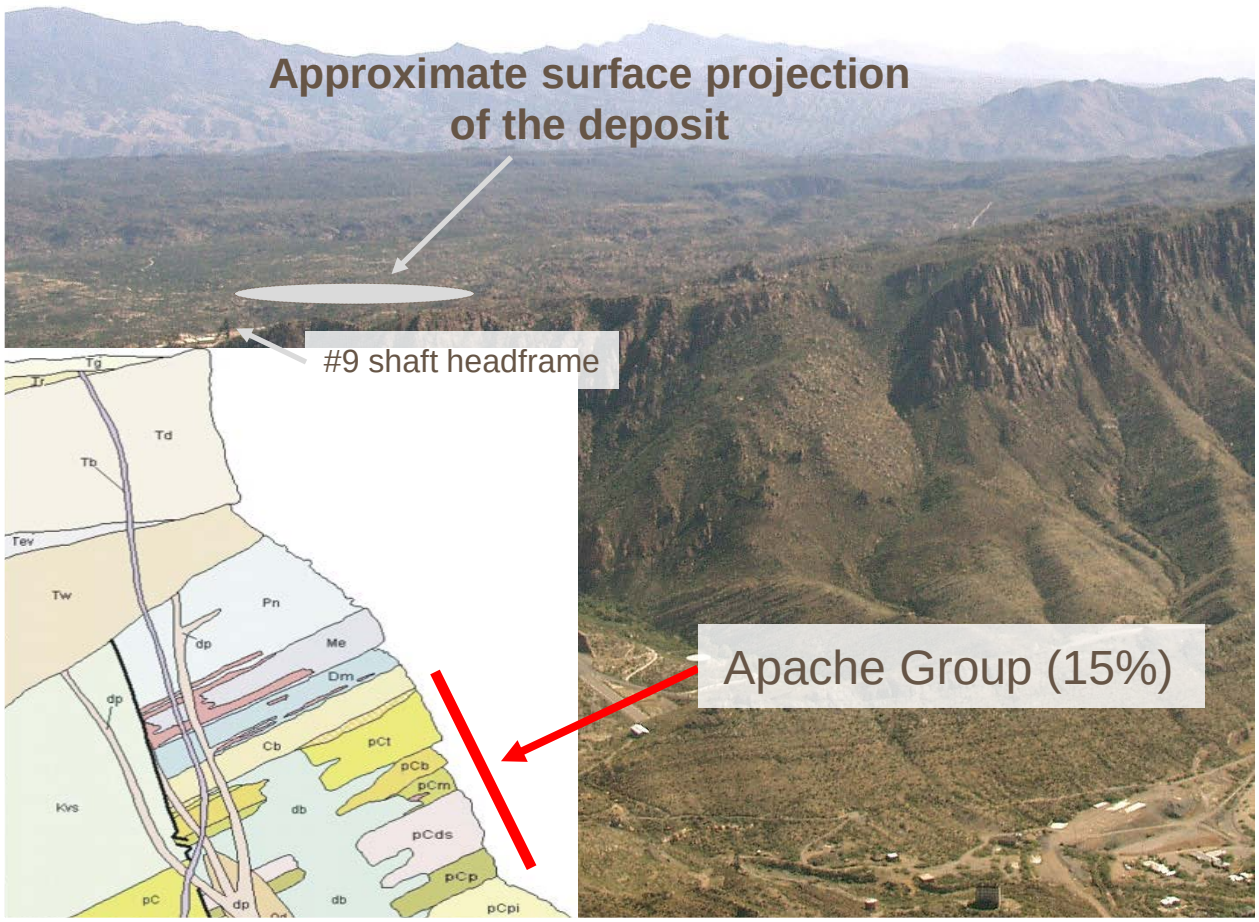
Resolution stratigraphy – Pinal Schist 1.7Ga

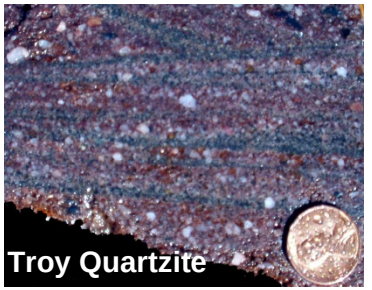


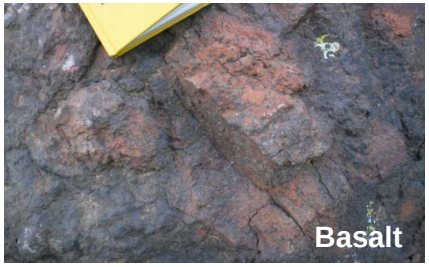
(%) – wt. percent of material hosted by rock unit within 1% Cu shell

Source: Resolution Copper Mining Limited

Resolution stratigraphy – Apache Group 1.4Ga



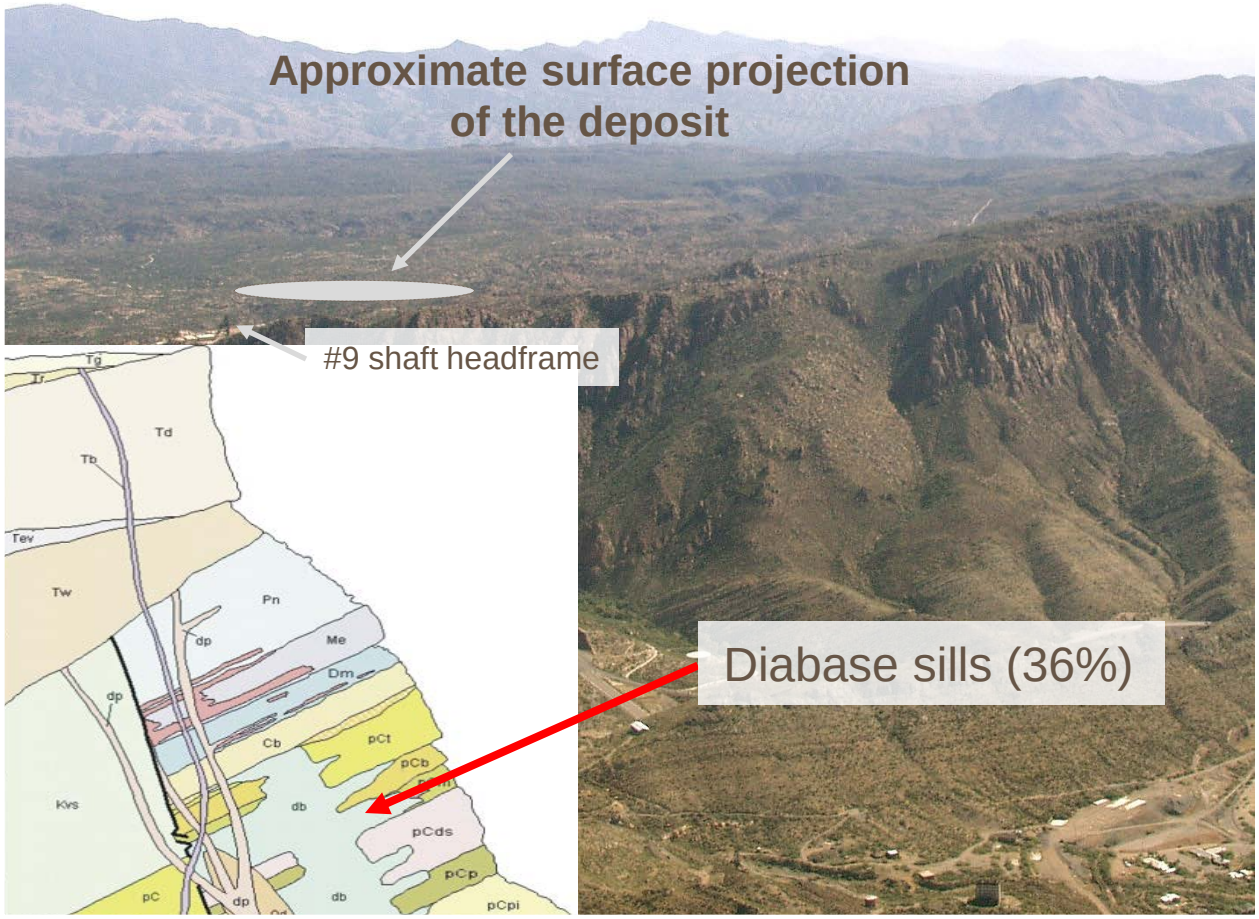




(%) – wt. percent of material hosted by rock unit within 1% Cu shell

Source: Resolution Copper Mining Limited

Resolution stratigraphy – Diabase sills 1.1Ga

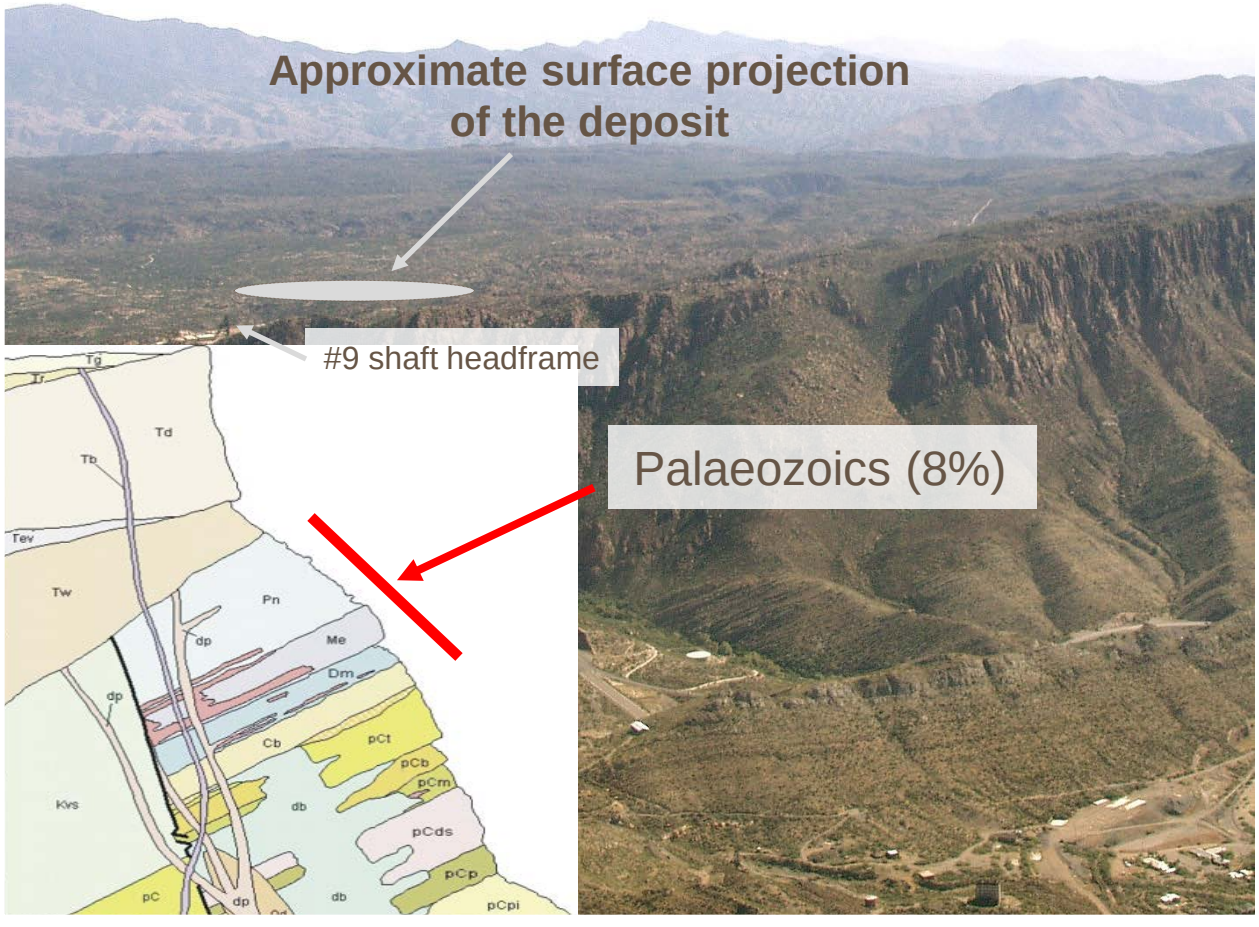


Diabase

(%) – wt. percent of material hosted by rock unit within 1% Cu shell

Source: Resolution Copper Mining Limited

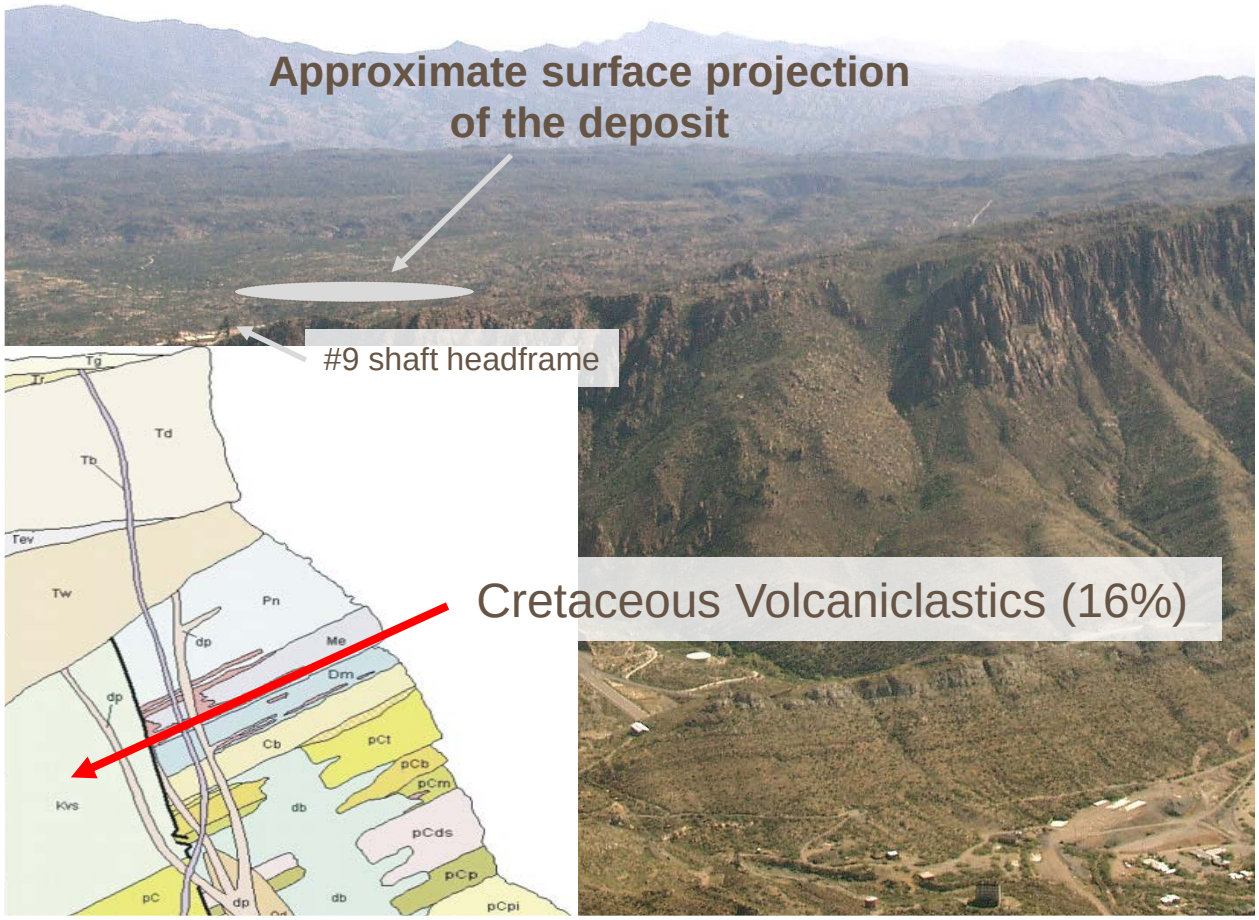
Resolution stratigraphy – Palaeozoic rocks

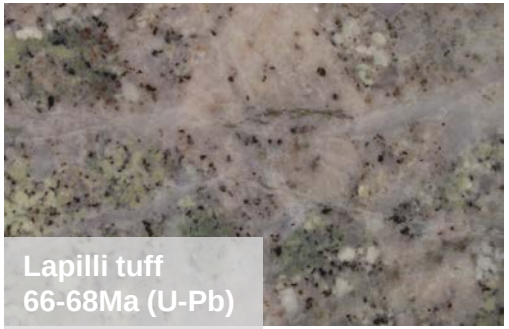


(%) – wt. percent of material hosted by rock unit within 1% Cu shell

Source: Resolution Copper Mining Limited

Resolution stratigraphy – Cretaceous rocks

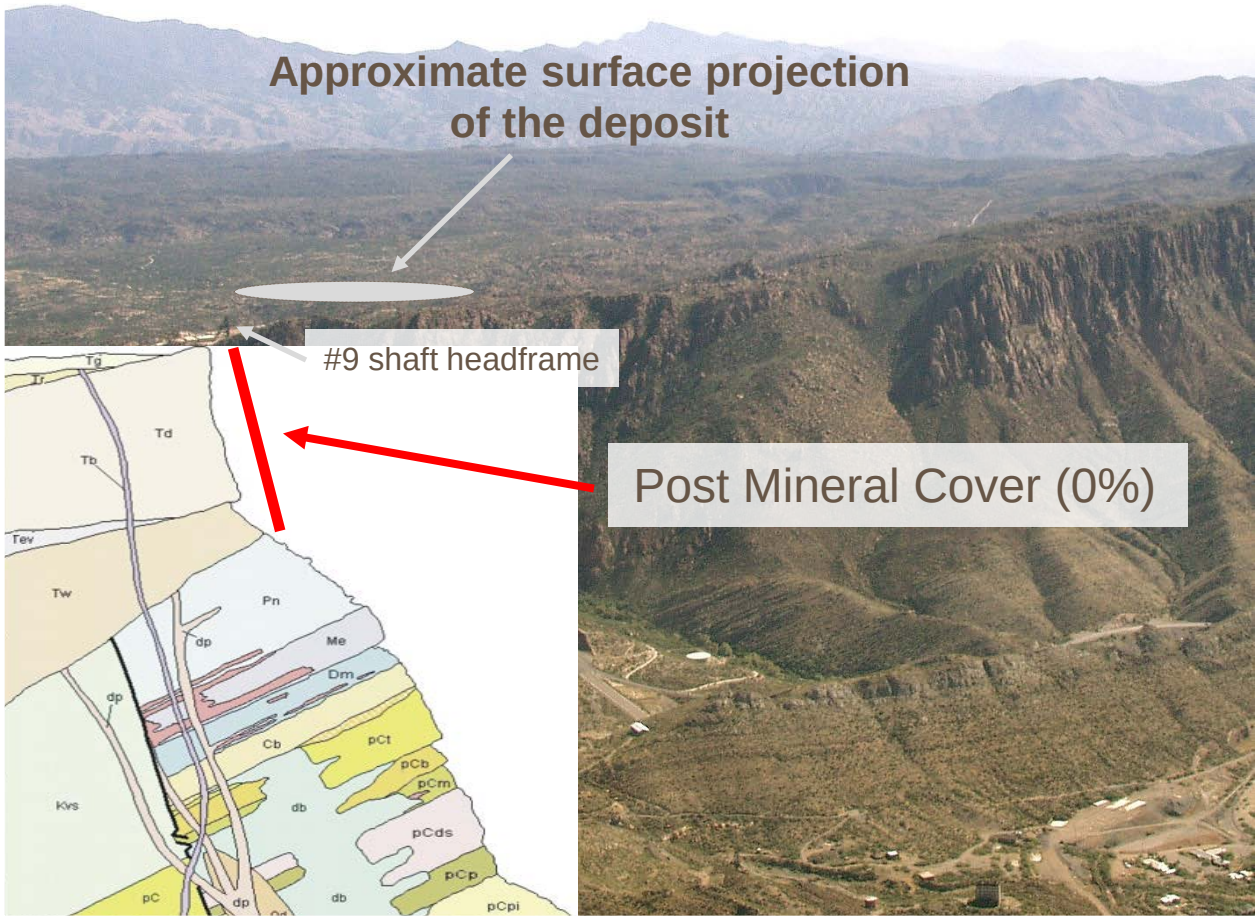


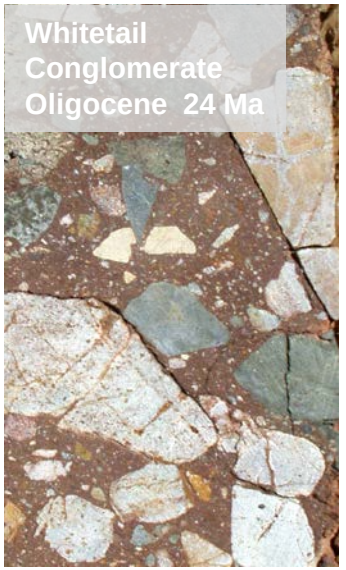


(%) – wt. percent of material hosted by rock unit within 1% Cu shell

Source: Resolution Copper Mining Limited

Resolution stratigraphy – Tertiary cover rocks

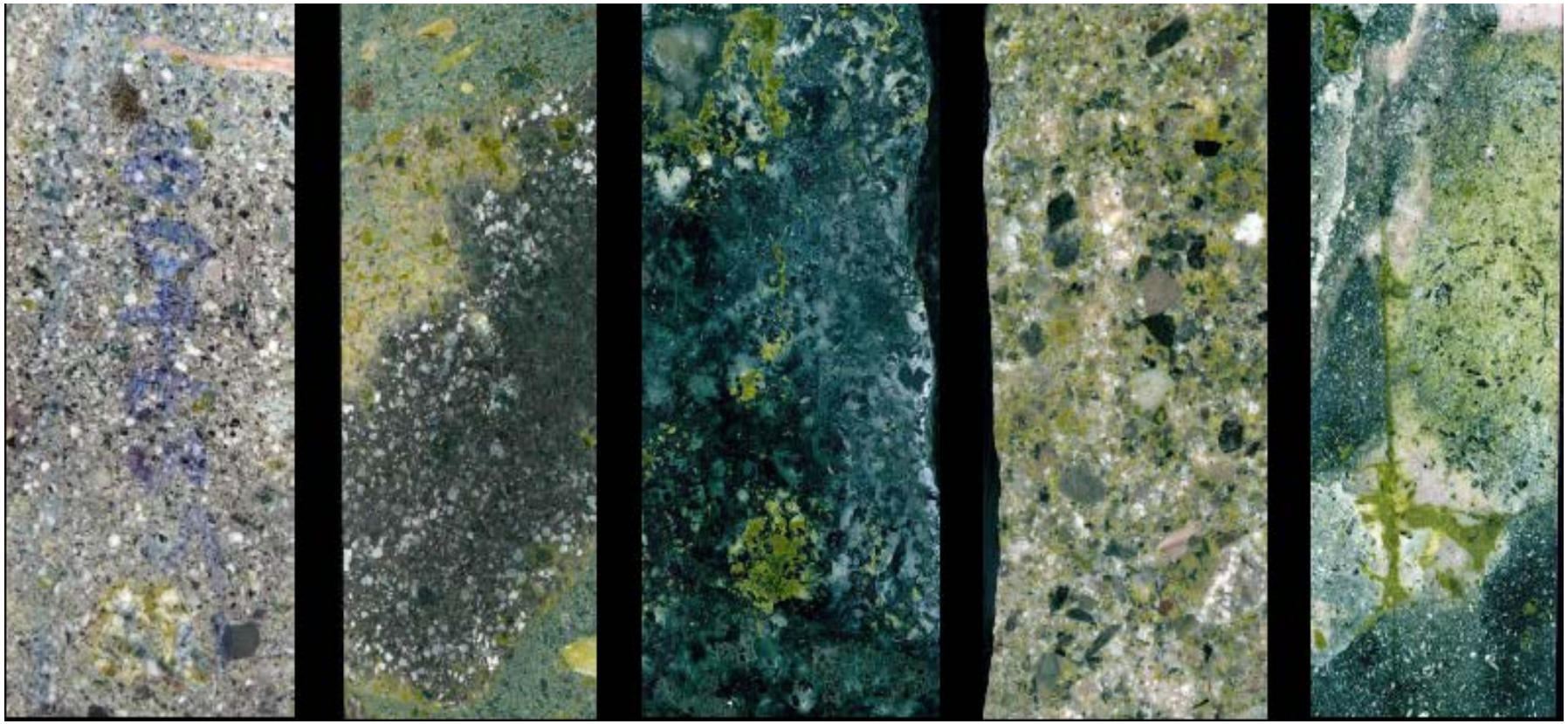




(%) – wt. percent of material hosted by rock unit within 1% Cu shell

Source: Resolution Copper Mining Limited

Propylitic alteration – early stage

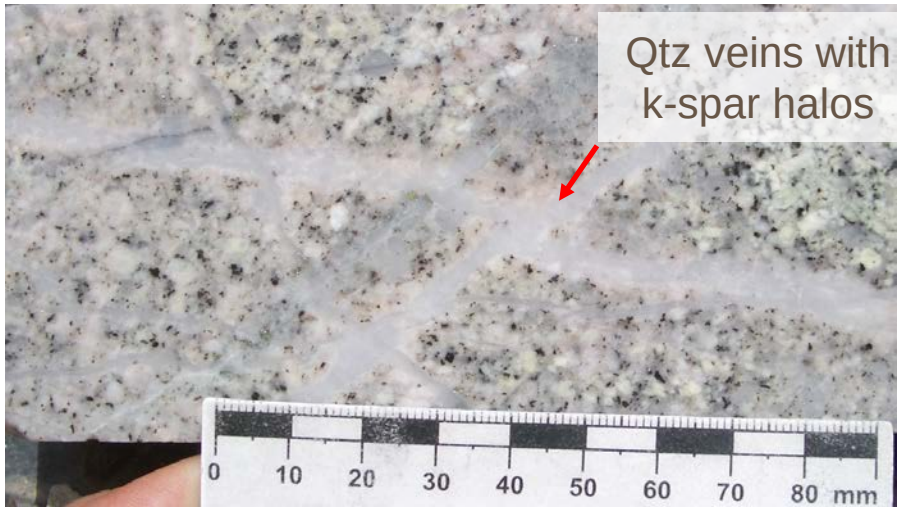


chlorite epidote illite	chlorite epidote, illite montmorillinite	epidote pyrite	chlorite epidote, pyrite montmorillinite	chlorite epidote, illite montmorillinite pyrite

increasing alteration intensity

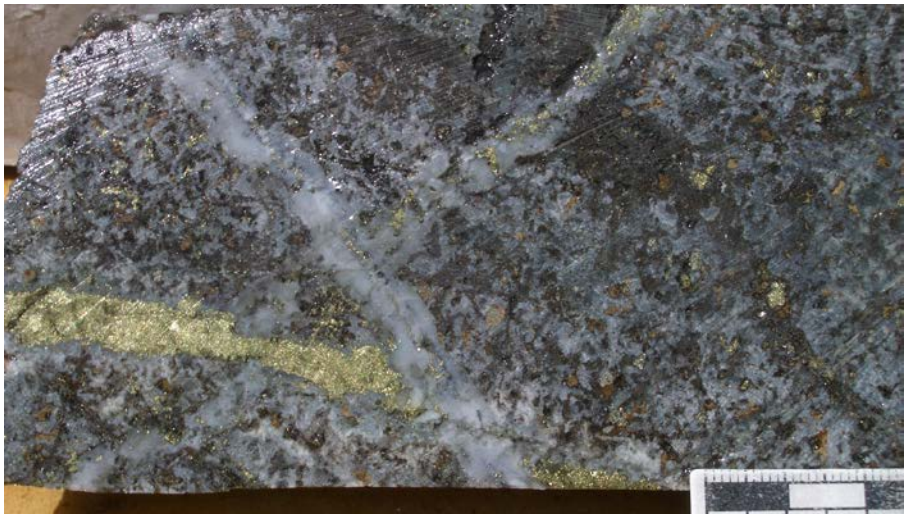
Source: Resolution Copper Mining Limited

Potassic alteration – early stage



Rhyodacite Porphyry

- biotite ± k-feldspar ± anhydrite ± magnetite
- chalcopyrite + molybdenite + pyrite ± bornite
- Ar-Ar (secondary biotite) yields 62-63 Ma ages



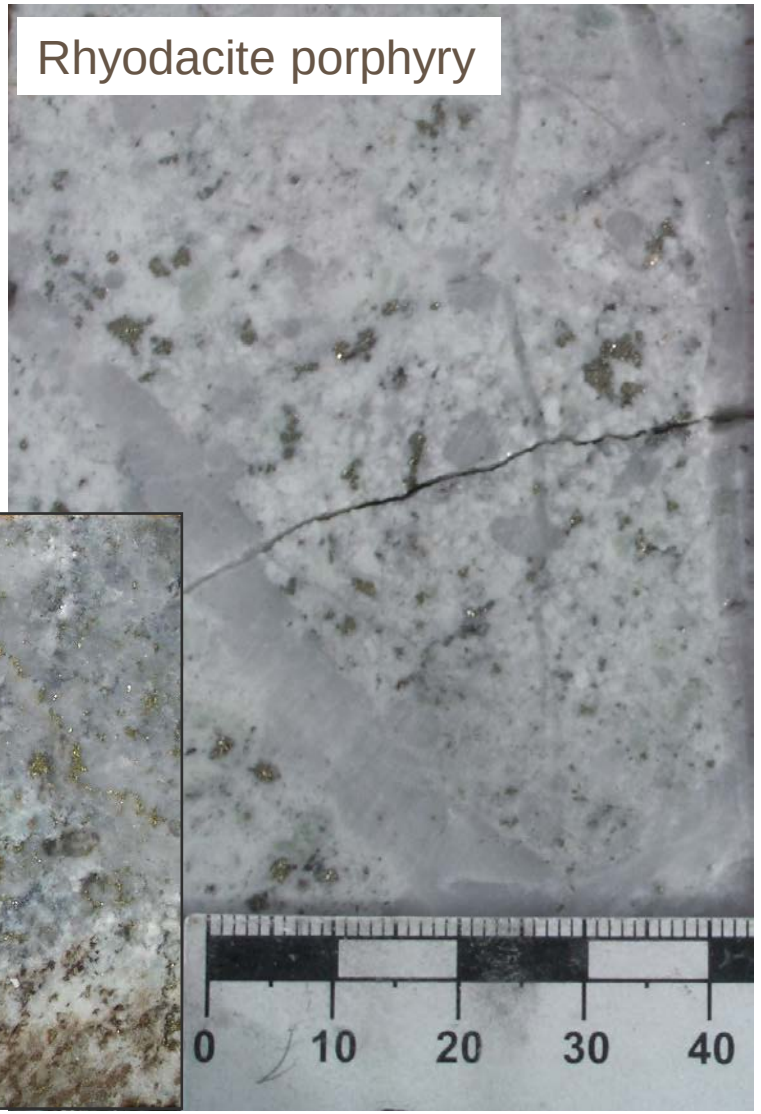
Diabase

Porphyry

Source: Resolution Copper Mining Limited

Phyllic alteration - intermediate stage

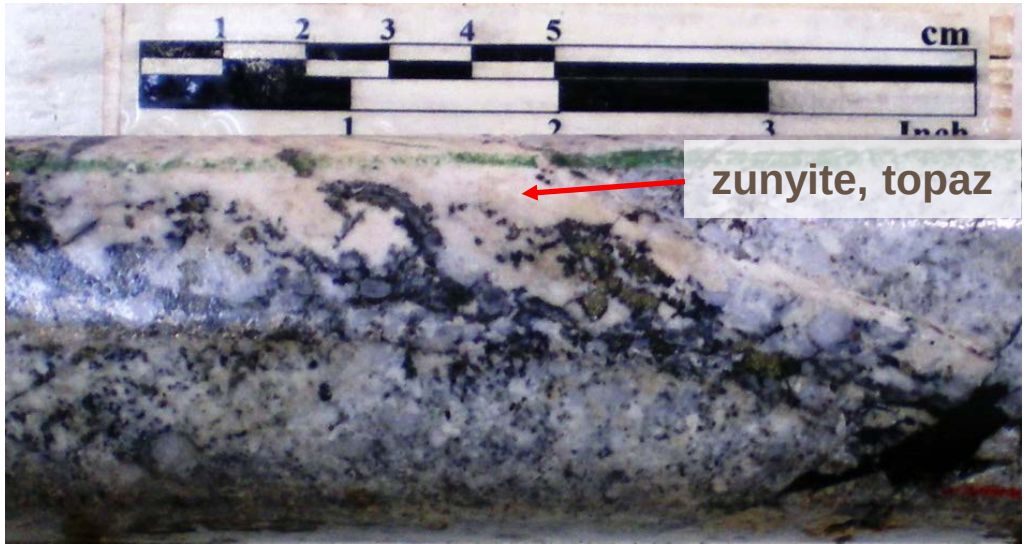
- quartz + sericite ± kaolinite
- early chalcopyrite + pyrite
- late chalcocite - digenite ± bornite ± pyrite
- Ar-Ar (sericite) ages of 62-63 Ma

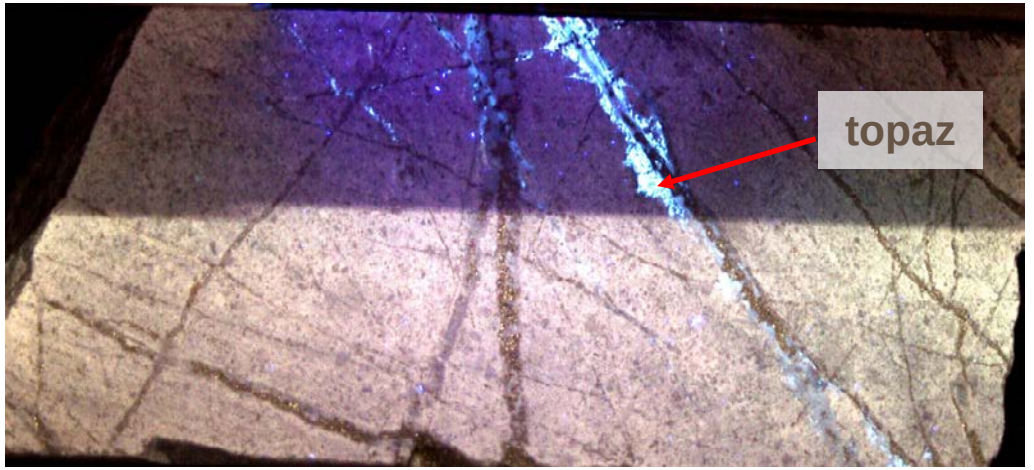


Source: Resolution Copper Mining Limited

Advanced argillic alteration – late stage

- kaolinite + dickite ± topaz ± quartz (± pyrite ± alunite ± zunyite)
- chalcocite - digenite + bornite ± covellite + pyrite
- Ar-Ar hypogene alunite 60-62 Ma





Source: Resolution Copper Mining Limited

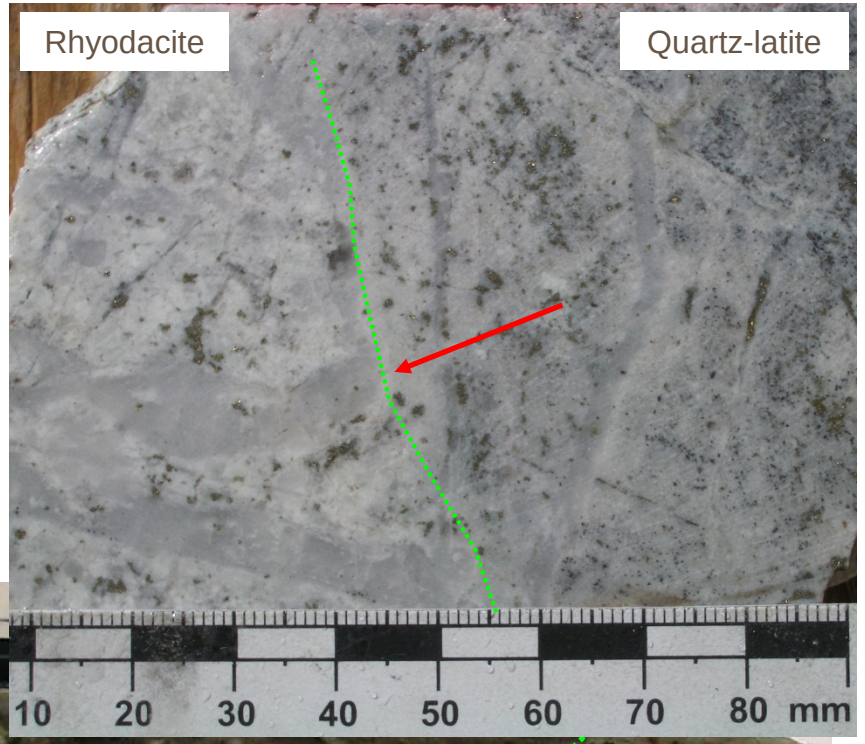
Alteration of limestones - skarns

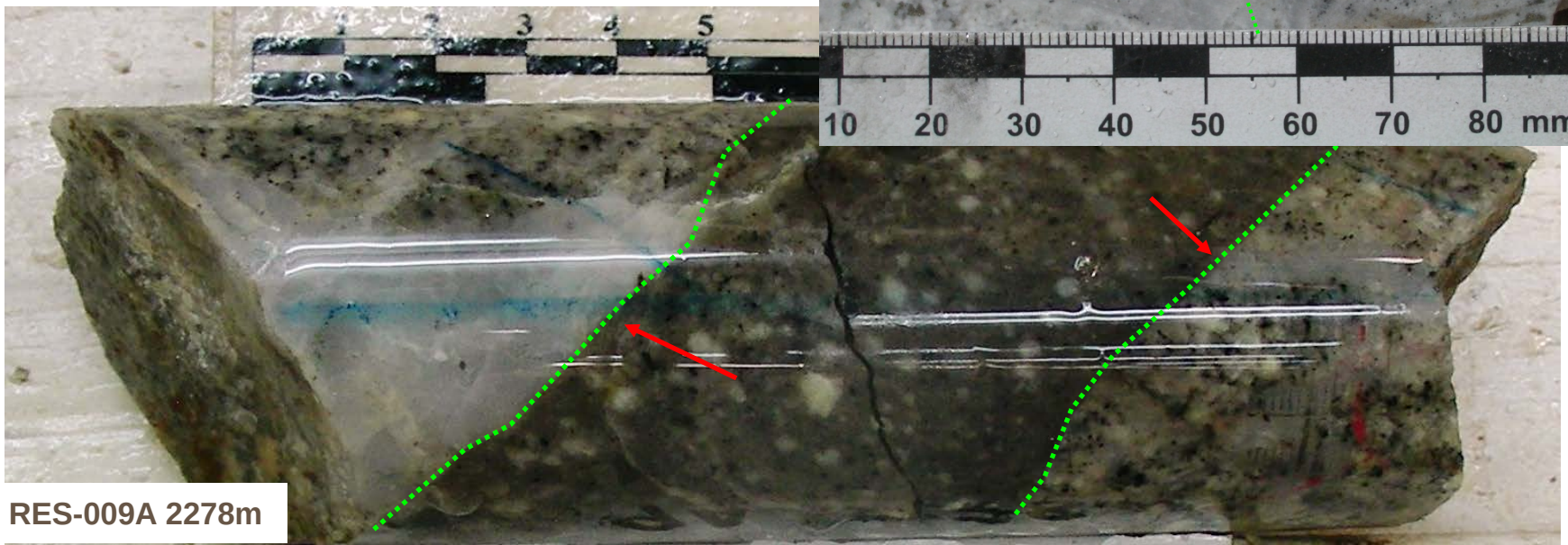
- Prograde (anhydrous skarn)
  garnet ± diopside ± magnetite
- Retrograde (hydrous skarn)
  tremolite ± actinolite ± chlorite ±
  epidote ± hematite ± chalcopyrite

Source: Resolution Copper Mining Limited

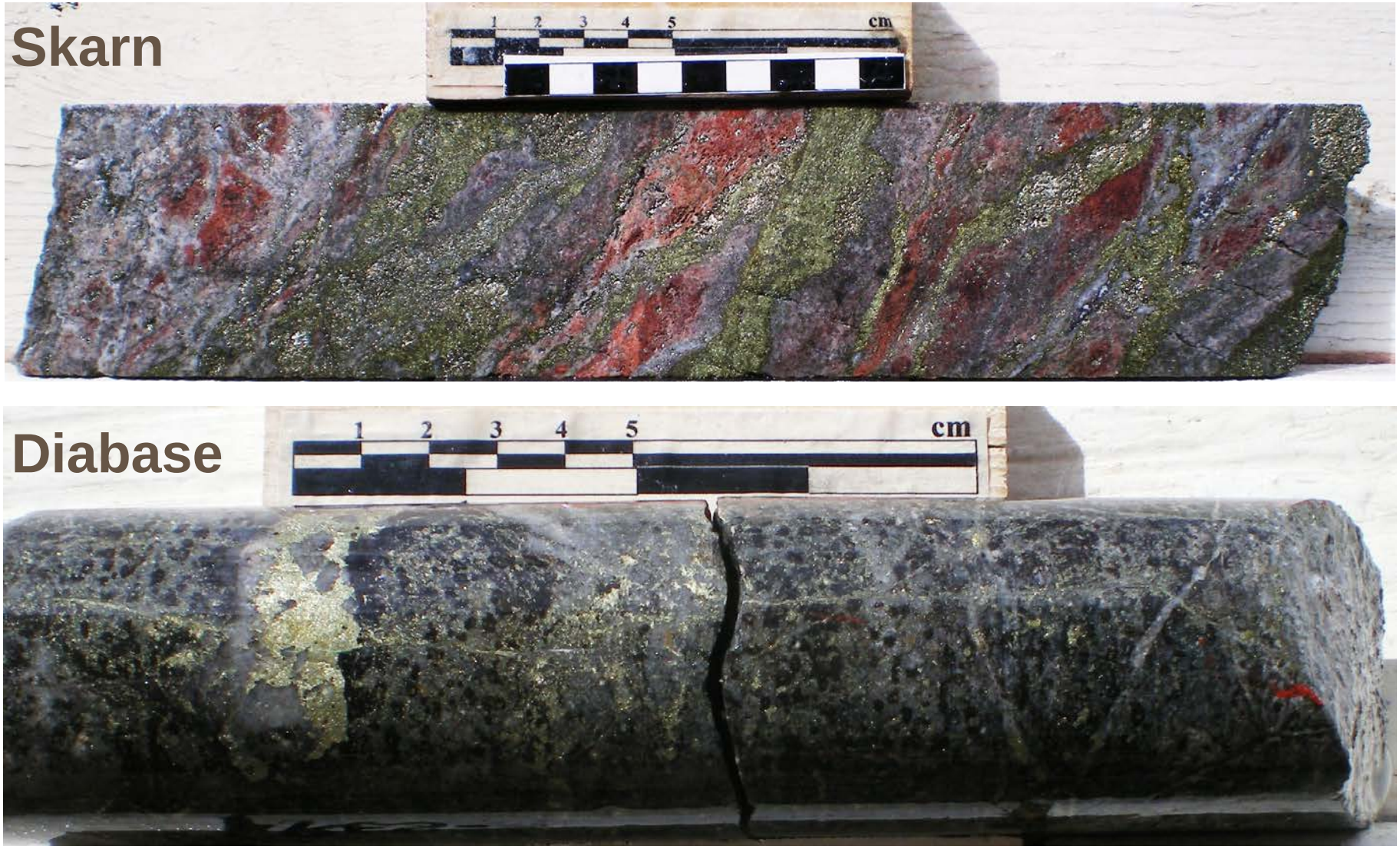
Temporal relationships between intrusions (16%) Truncated veins

- 3 families of porphyries based on U-Pb dates of 66-69Ma.
  - Rhyodacite
  - Quartz latite
  - Crowded latite porphyry (minor)
- Porphyries appear to be pre- to early-mineral





High grade host rocks – skarn and diabase



Source: Resolution Copper Mining Limited

High grade host rocks – hydrothermal breccias

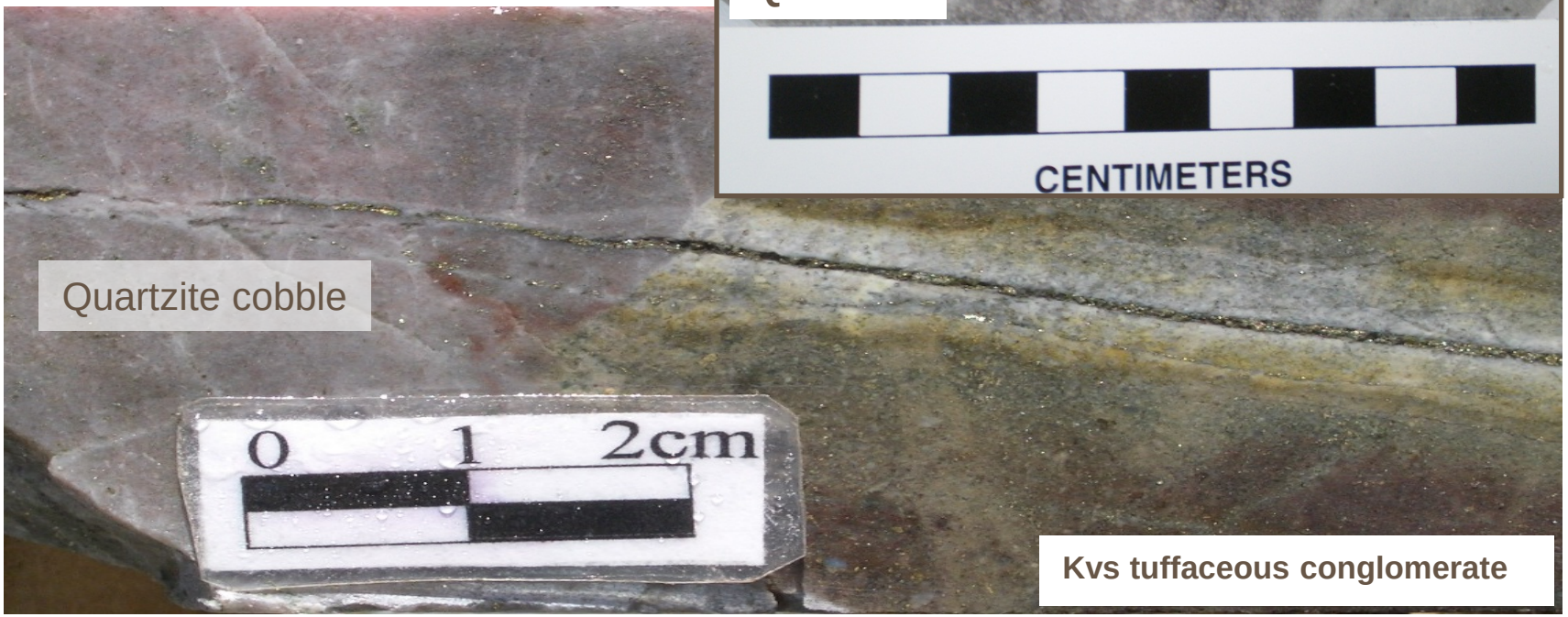
- pre- to very early-mineral
- pre- and post-porphyry
- breccias host 10% of the resource

Source: Resolution Copper Mining Limited

Host rock control on alteration and mineralisation

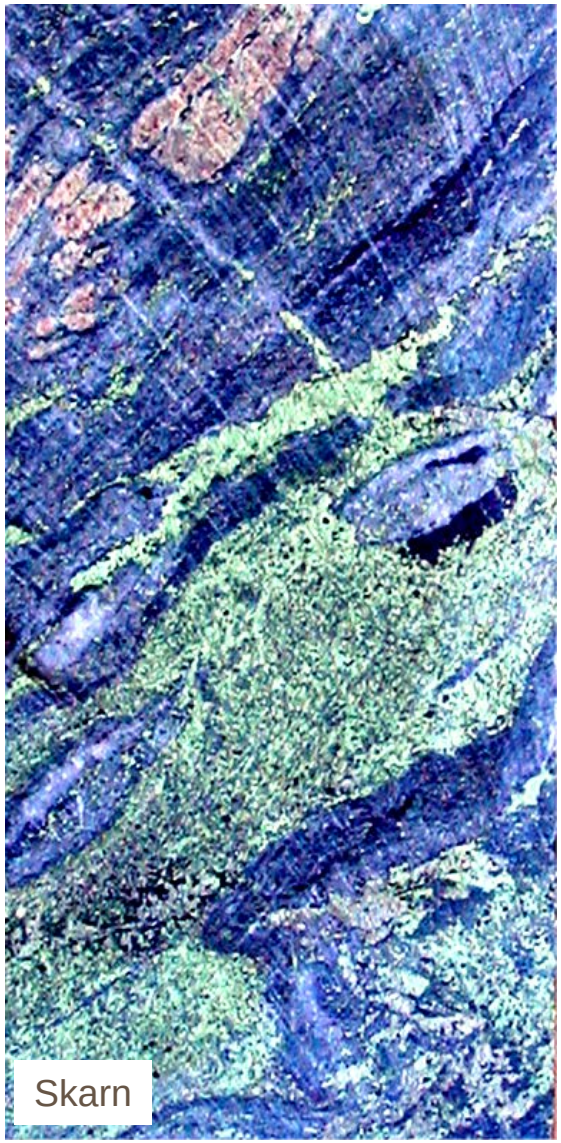
Geochemically inert lithologies
i.e. quartzite, felsic intrusives

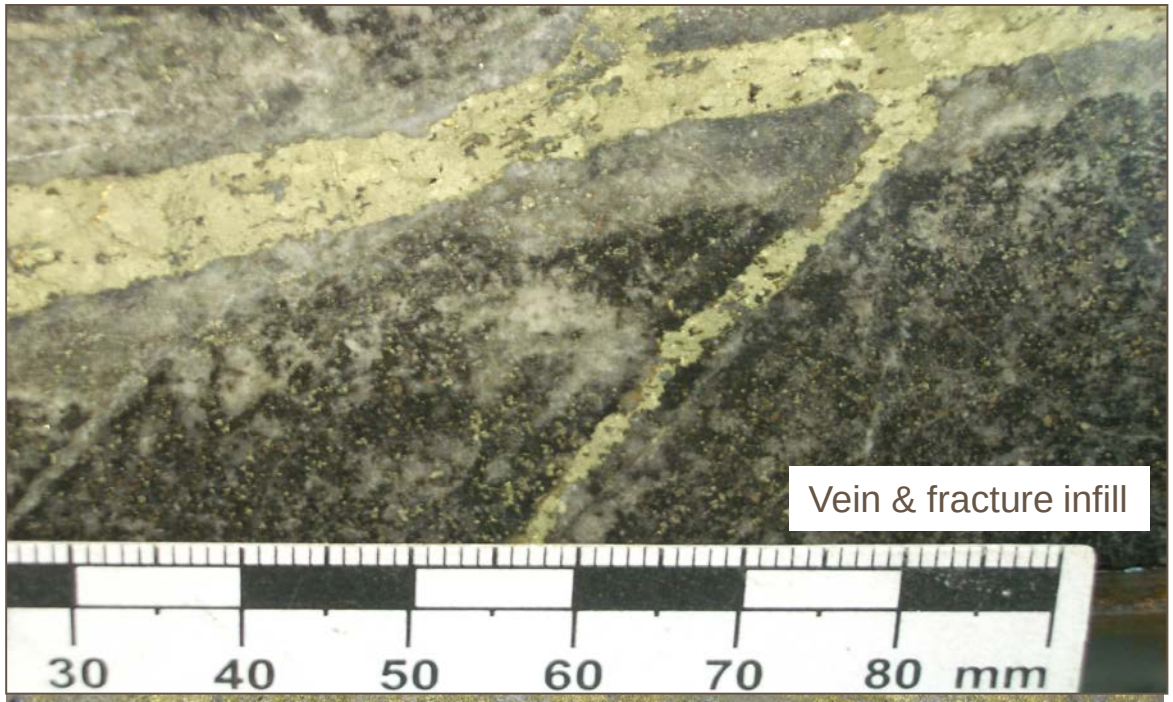
- No fluid buffering capacity
- Cu remains mobile
- Host to high Mo grades

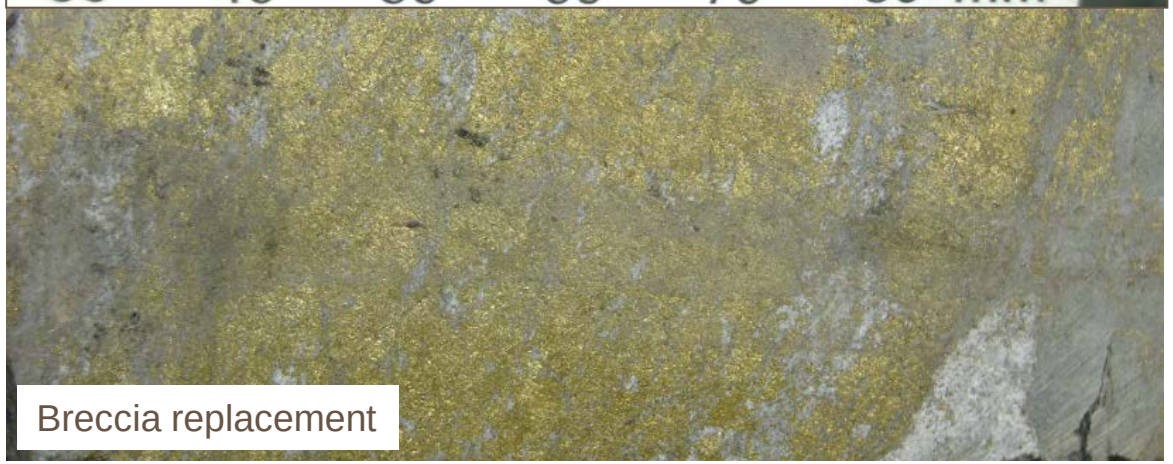


Source: Resolution Copper Mining Limited

Main-stage hypogene chalcopyrite



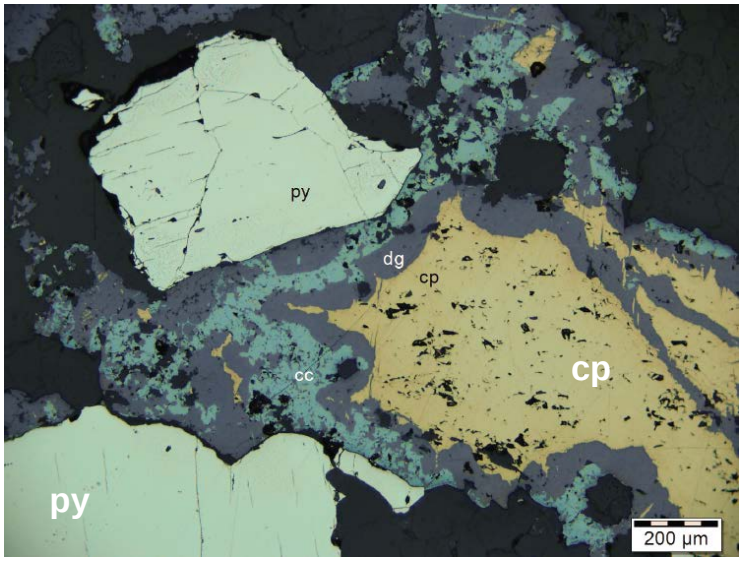


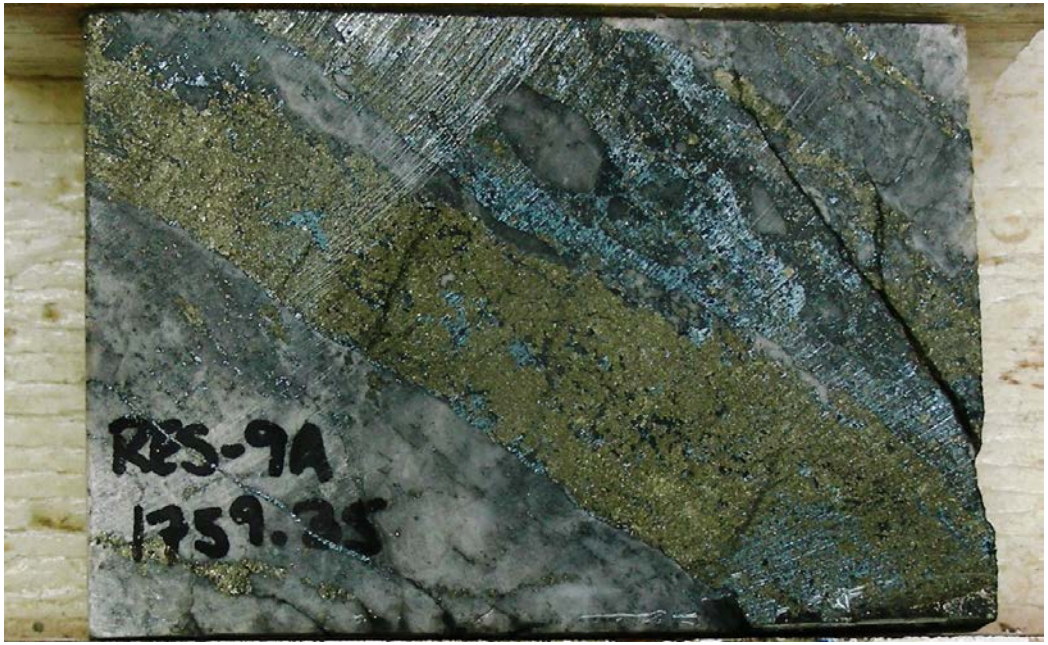


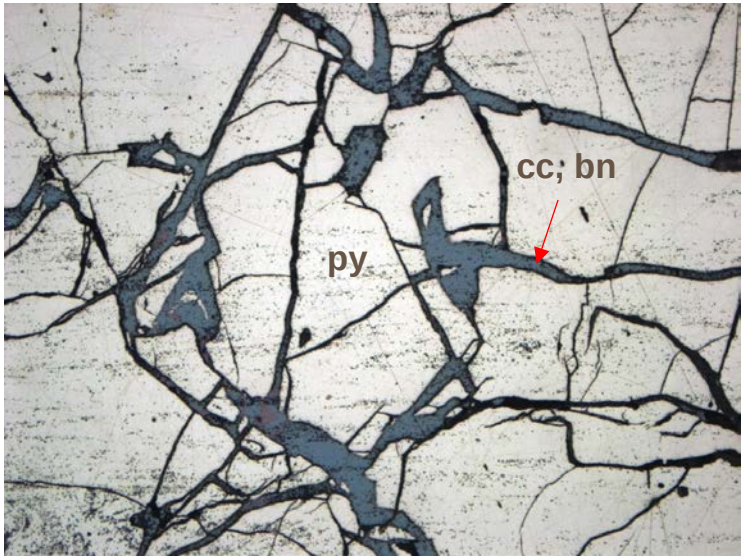
Source: Resolution Copper Mining Limited

Hypogene overprinting

- Progressive sulphidation as fluids evolve
- Assemblages include bornite, digenite, chalcocite, covellite and pyrite

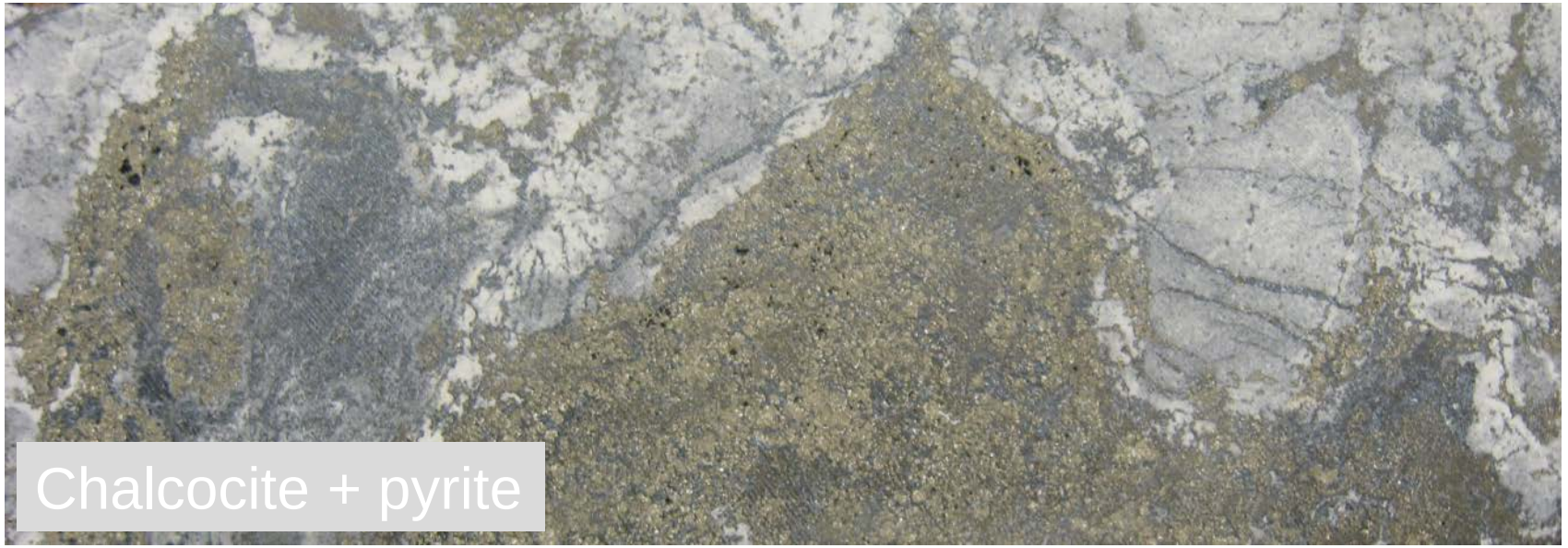






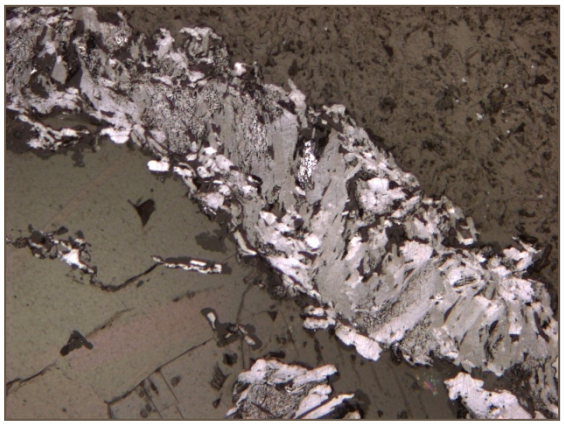
Source: Resolution Copper Mining Limited

Hypogene overprinting – high grade breccia

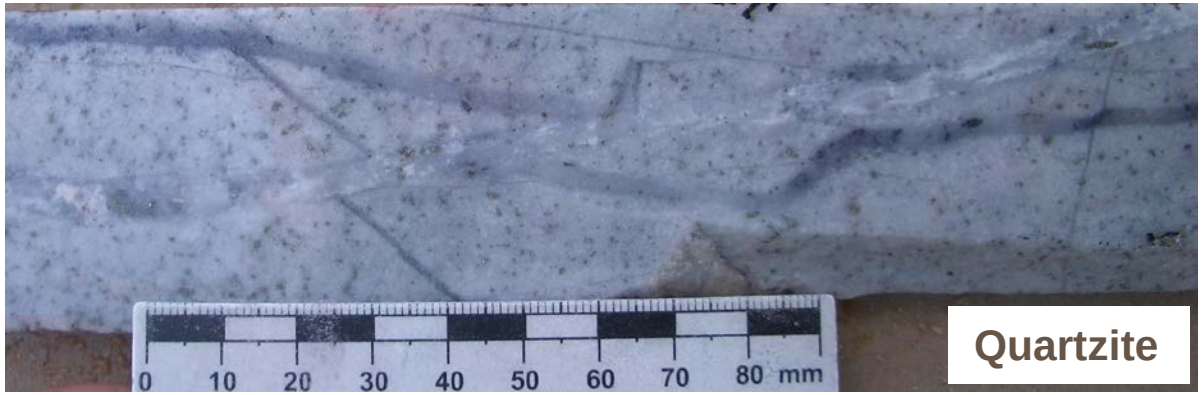


Molybdenite

- Molybdenum (350 ppm)
- Most quartz-molybdenite veins are associated with transitional K silicate – QSP alteration.
- Classic “B” veins of Gustafson and Hunt (1975).
- Re-Os ages of 64-65 Ma



RES-004B, 1,757m
Rhyodacite porphyry
1.3% Cu, 0.3% Mo

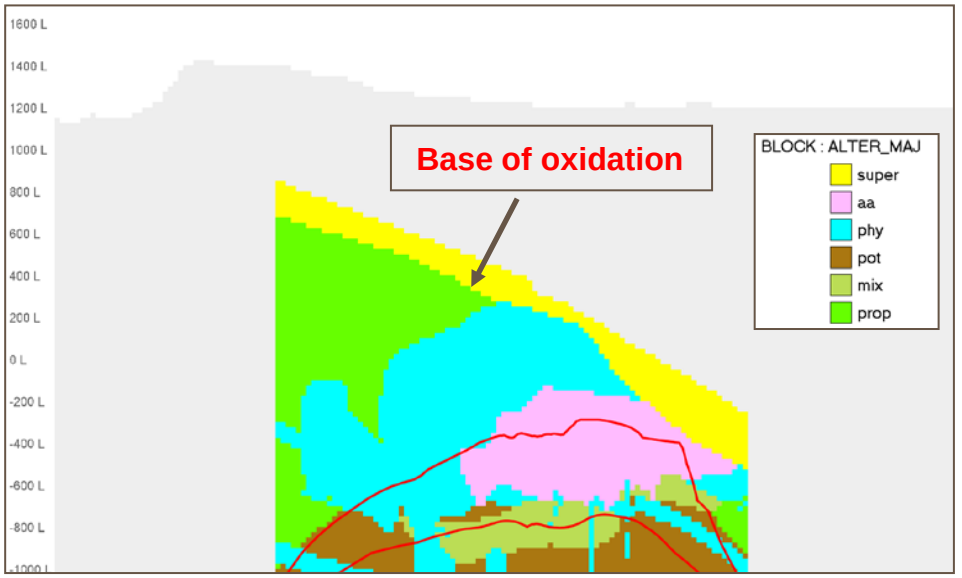


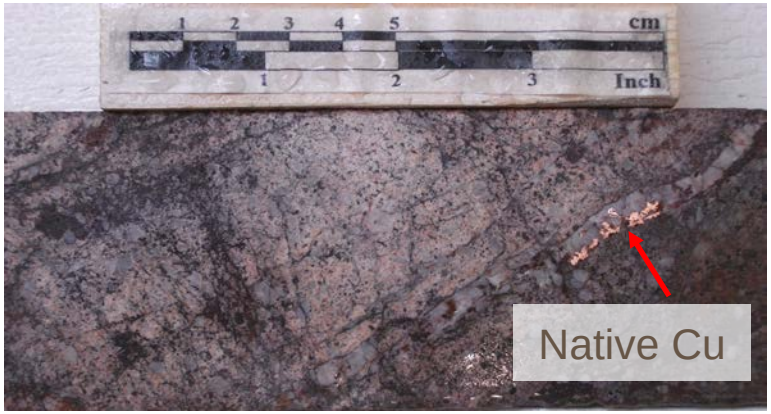
Quartzite

Source: Resolution Copper Mining Limited

Supergene processes

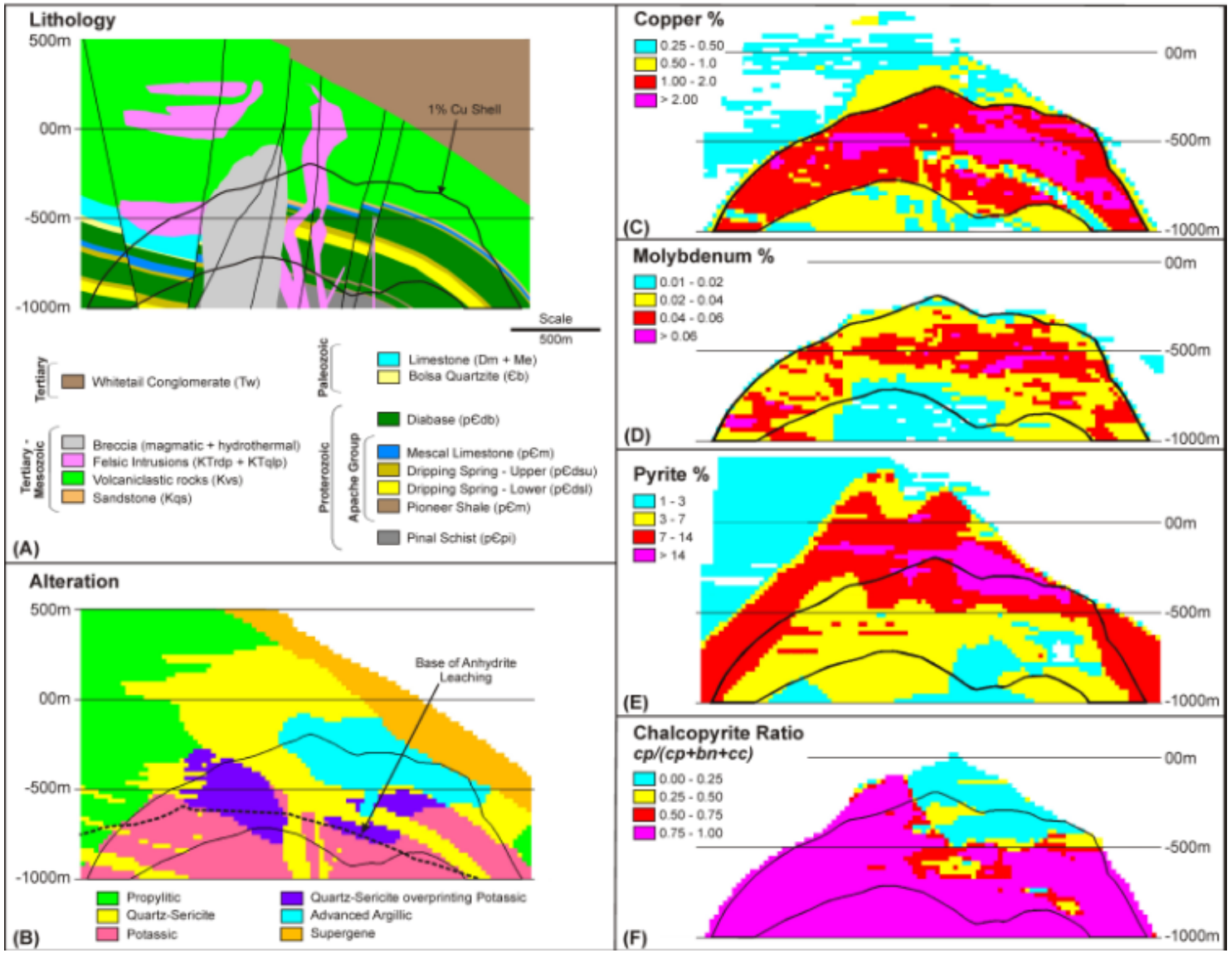
- Leached cap 30-250m thick
- Hematite-goethite rich with local native Cu
- No significant secondary chalcocite
- No secondary oxide minerals





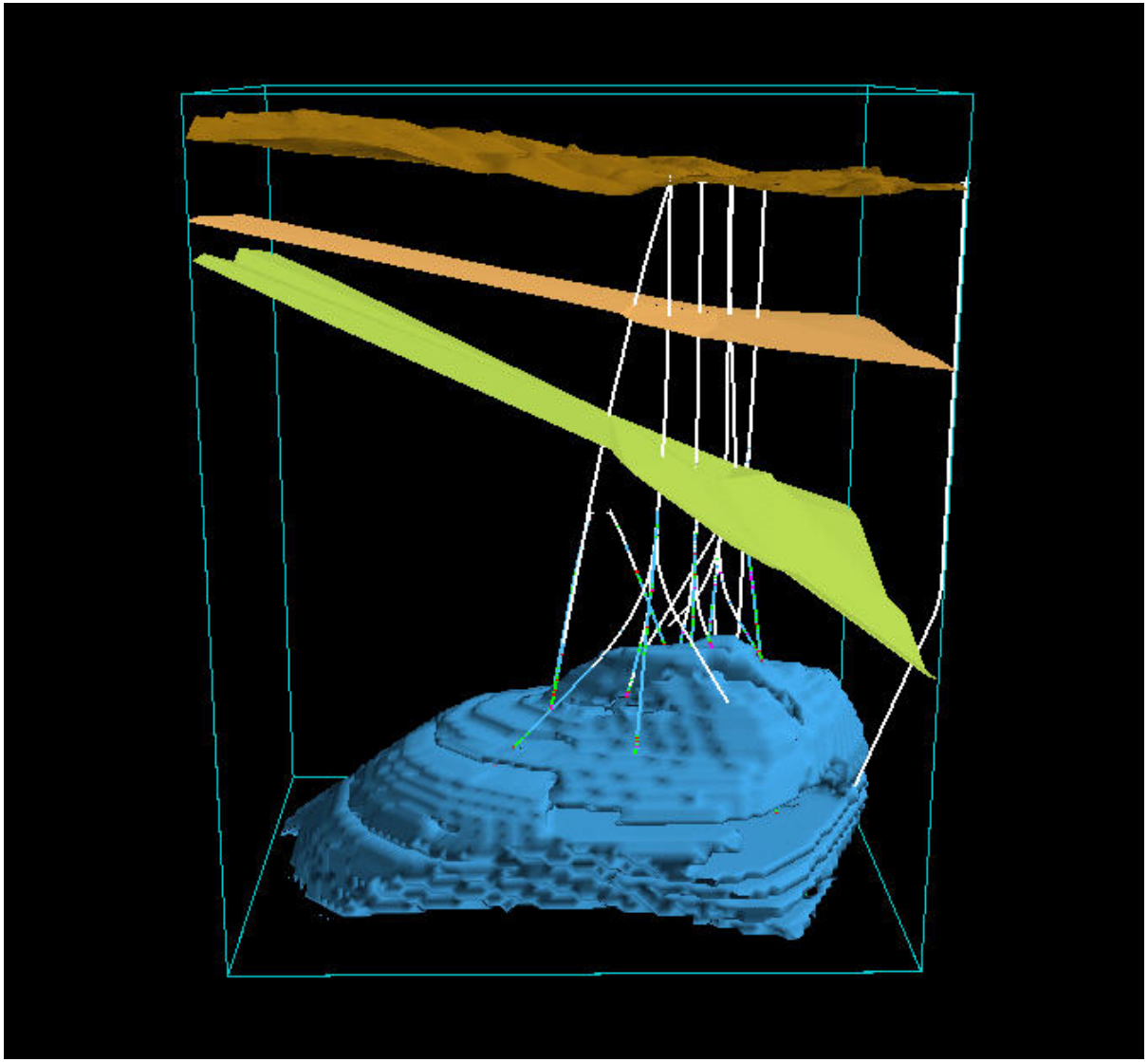
Source: Resolution Copper Mining Limited

Resolution – geology, alteration and mineralisation



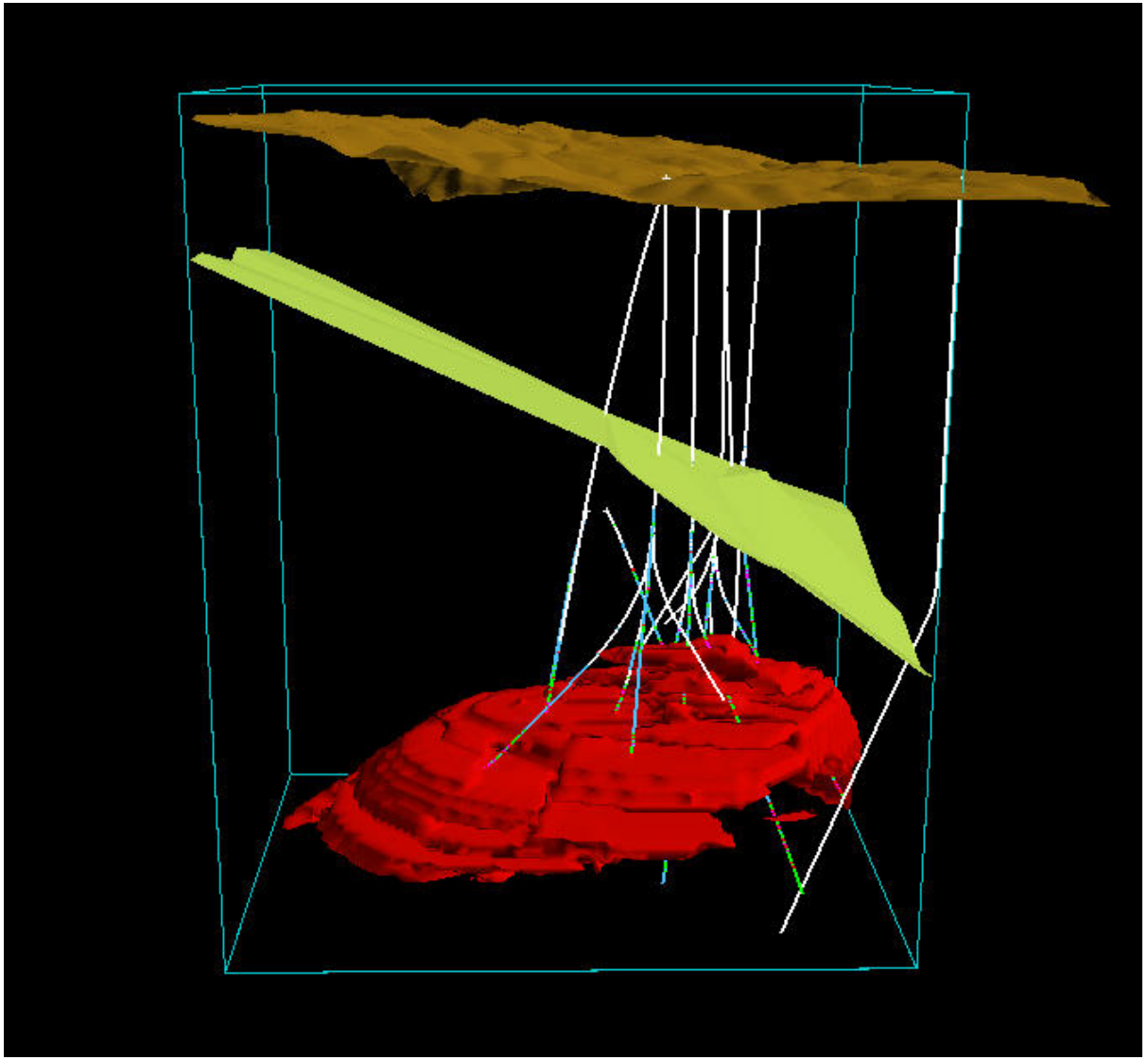
Source: Hehnke et al., 2012

Resolution >0.5% copper shell



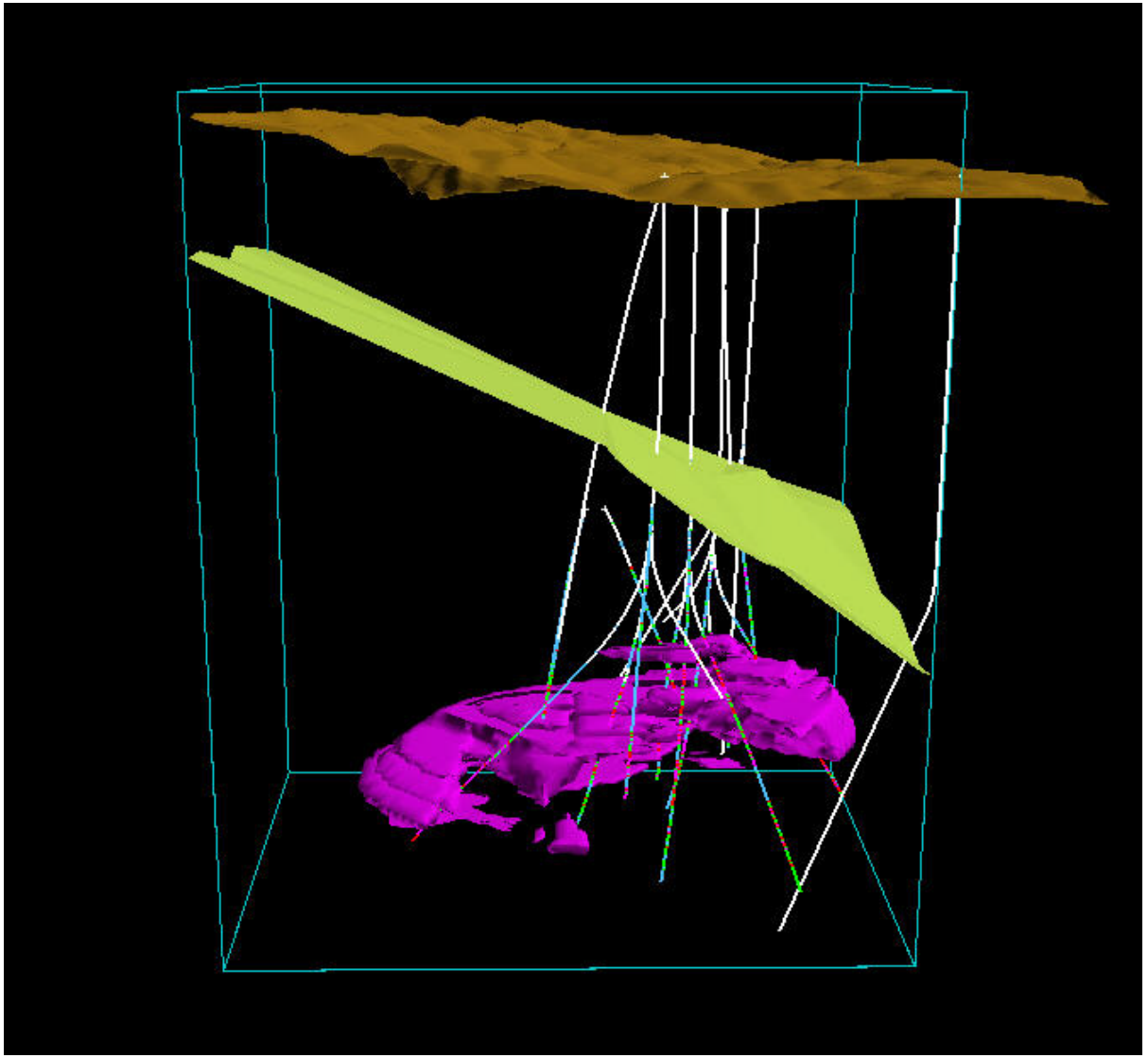
Source: Resolution Copper Mining Limited

Resolution >1.5% copper shell



Source: Resolution Copper Mining Limited

Resolution >2% copper shell

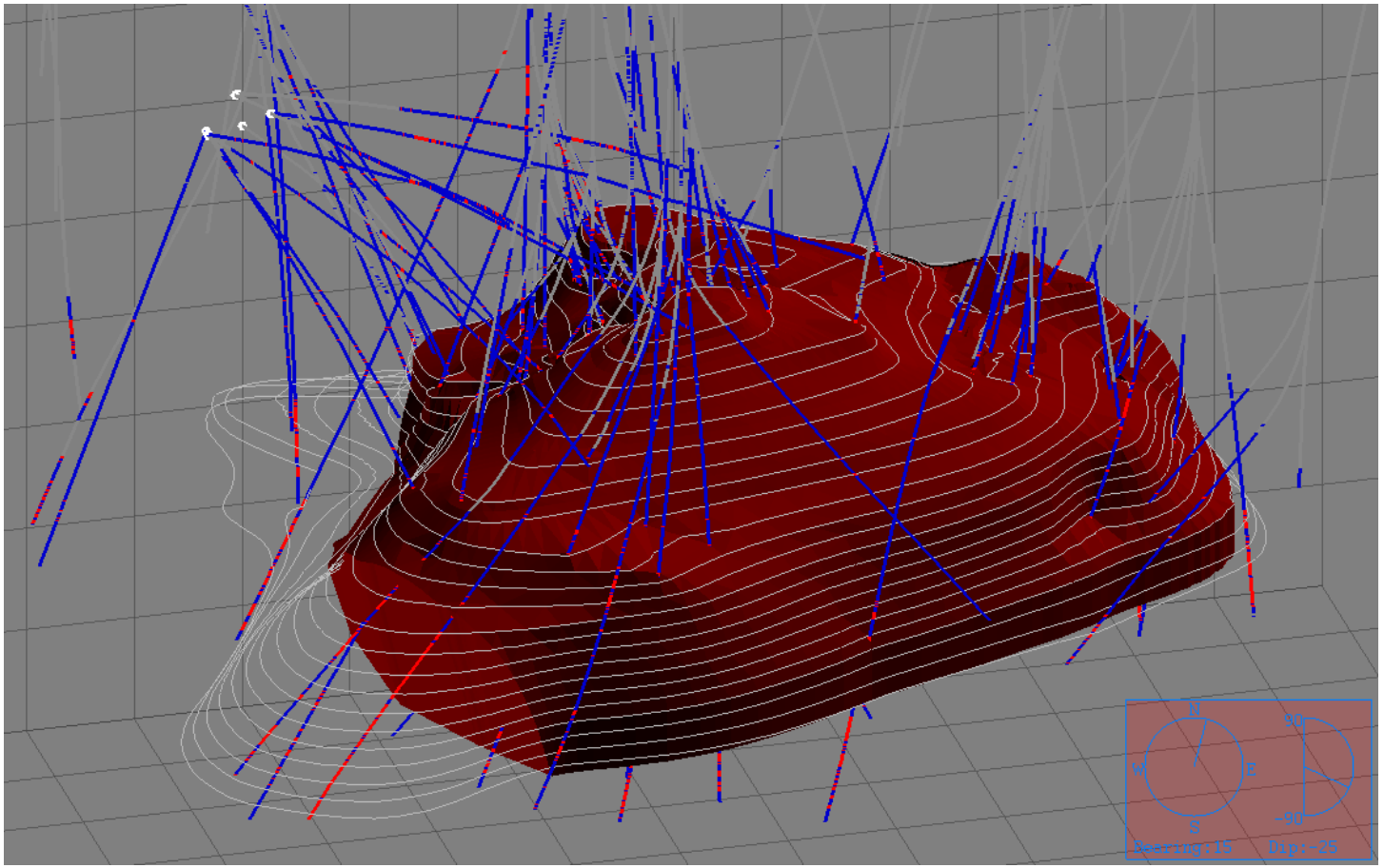


Source: Resolution Copper Mining Limited

Resolution Resource

2012 JORC Inferred Resource
1.737 Bt @ 1.52% Cu & 0.035% Mo

Model Year	M Tonnes	% Cu	% Mo
2012	1,736	1.52	0.035
2009	1,624	1.47	0.037
Difference	112	0.05	-0.002



Source: Resolution Copper Mining Limited

Why is the hypogene grade of Resolution so high?

- Favourable host rocks; diabase and limestone (hosting 47% of mineralization) *cf. El Teniente, Hugo Dummett*
- Fluid flux focused through centrally located pre- and syn-mineral breccias that provided conduits through sub-horizontal diabase sills.
- Absence of late (diluting) intrusions and breccias *cf. Chuquicamata*
- Multiple phases of copper addition? *cf. Hugo Dummett*